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Tonopah Test Range Air Monitoring: CY2015 Meteorological, Radiological, and Airborne Particulate Observations

Prepared by

George Nikolich, Craig Shadel, Jenny Chapman, Greg McCurdy,
Vicken Etyemezian, Julianne J. Miller, and Steve Mizell

Submitted to

Nevada Field Office
National Nuclear Security Administration
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September 2016

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EXECUTIVE SUMMARY

In 1963, the U.S. Department of Energy (DOE) (formerly the Atomic Energy Commission [AEC]), implemented Operation Roller Coaster on the Tonopah Test Range (TTR) and an adjacent area of the Nevada Test and Training Range (NTTR) (formerly the Nellis Air Force Range). The operation resulted in radionuclide-contaminated soils at the Clean Slate I, II, and III sites. This report documents observations made during ongoing monitoring of radiological, meteorological, and dust conditions at stations installed adjacent to Clean Slate I and Clean Slate III, and at the TTR Sandia National Laboratories (SNL) Range Operations Control (ROC) center. The primary objective of the monitoring effort is to determine if winds blowing across the Clean Slate sites are transporting particles of radionuclide-contaminated soil beyond the physical and administrative boundaries of the sites.

Three monitoring stations are in operation as follows: Station 400 near the SNL ROC, and Stations 401 and 402 along the northwest perimeter fence lines of the Clean Slate III and Clean Slate I sites, respectively. The stations are downwind of the contaminated area during south-southeast winds, one of the two predominant wind directions through the area (the other being from the north-northwest). The stations—similar in design to the Community Environmental Monitoring Program (CEMP) stations operating at locations surrounding the Nevada National Security Site and TTR—include meteorological instruments, continuous-flow low-volume air samplers, pressurized ionization chambers for measuring gamma energy, saltation sensors, and saltation traps. Data are recorded for ten-minute intervals on data loggers, and hourly averages are uploaded via a satellite system to the Western Regional Climate Center at Desert Research Institute. Air filter samples are collected biweekly and material in the saltation traps is collected as a sufficient sample for analysis accumulates (at a 14 month and 8 month interval thus far).

Soil transport by suspension increases approximately exponentially with linearly increasing wind speed, although concentrations of PM_{10} (particulate matter of aerodynamic diameter of less than 10 micrometers, an indicator of small particles that are suspended in the air and can be easily inhaled) remain low until winds exceed approximately 32 km/hr (20 mph). Wind speeds in excess of 32 km/hr occur less than three percent of the time. High winds are associated with two predominant directions: north-northwest and south-southeast, although winds over 40 km/hr (25 mph) occur more frequently from the north-northwest than the south. A strong wind event on April 15, 2015, was driven by northwest winds and included gusts over 64 km/hr (40 mph).

Radionuclide assessment of airborne particulates in 2015 found the gross alpha and gross beta values of dust collected from the filters at the monitoring stations are consistent with background conditions as approximated by data from surrounding CEMP stations. Gamma spectral analyses of the air filters identified only naturally occurring radionuclides. Ambient gamma radiation measurements indicate that the average annual gamma exposure rate is similar at all three monitoring stations, and periodic intervals of slightly increased gamma values appear to be associated with storm fronts passing through the area.

Soil transport by saltation is also strongly dependent on wind speed. As wind speed increases past a threshold value of approximately 24 to 32 km/hr (15 to 20 mph), particle counts increase roughly exponentially. Saltation counts and PM_{10} concentration have a strong linear relationship. Material was collected from the saltation traps for the first time during 2015 and analyzed using alpha spectroscopy. Concentrations of plutonium in the collected sand are above background levels, though below risk-based action levels. The absence of a consistent difference in concentration between samples that are upwind or downwind from the contaminated areas suggests that the baseline concentrations of contaminants were already elevated in the area prior to trap placement. Therefore, the trap samples do not necessarily indicate movement of contamination away from the fenced site, but the presence of plutonium in the saltation traps does demonstrate that plutonium is moving by saltation in the environment.

The meteorological and particle monitoring indicate that conditions for wind-borne contaminant movement exist at the Clean Slate sites and that although the transport of radionuclide-contaminated soil by suspension has not been detected, movement by saltation is occurring.

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LIST OF ACRONYMS

AEC	Atomic Energy Commission
BSNE	Big Spring Number Eight
CAU	Corrective Action Unit
CEMP	Community Environmental Monitoring Program
CS I	Clean Slate I
CS II	Clean Slate II
CS III	Clean Slate III
CY	Calendar year
DOE	Department of Energy
DRI	Desert Research Institute
GOES	Geostationary Operational Environmental Satellite
GZ	Ground zero
NNSA/NFO	National Nuclear Security Administration, Nevada Field Office
NTTR	Nevada Test and Training Range
PIC	Pressurized ionization chamber
PM	Particulate matter
ROC	Range Operations Center
RSL	Radiological Services Laboratory
SNL	Sandia National Laboratories
TDR	Time domain reflectometry
TTR	Tonopah Test Range
VWC	Volumetric water content
WRCC	Western Regional Climate Center

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INTRODUCTION

In May and June 1963, the U.S. Department of Energy (DOE) (formerly the Atomic Energy Commission [AEC]) implemented Operation Roller Coaster to evaluate the dispersal of radionuclides when nuclear devices were subjected to chemical explosions while in storage or transit (Dick *et al.*, 1963; Johnson and Edwards, 1996). The operation consisted of four tests, Double Tracks conducted in Stonewall Flat on the Nevada Test and Training Range (NTTR) and Clean Slate I, II, and III conducted in Cactus Flat on the Tonopah Test Range (TTR). The Clean Slate sites are the focus of this report and are located southeast of Tonopah, Nevada, in Nye County (Figures 1 and 2).

The primary purpose of the Clean Slate tests was to study plutonium dispersion from nonnuclear explosions of plutonium weapons (U.S. Department of Energy, 1996). The Clean Slate tests involved one weapon containing plutonium and several simulated weapons containing uranium (Dick *et al.*, 1963; Johnson and Edwards, 1996). For each test, data collection was distributed along arcs within a quarter-circle, wedge-shaped area that emanated from the test ground zero (GZ) and centered on a radius that extended from GZ to the south or southeast (Dick *et al.*, 1963; Johnson and Edwards, 1996), which were the expected downwind directions. Data collection during the tests focused on plutonium and uranium because of their radiological toxicity (Dick *et al.*, 1963). Subsequent surveys to characterize radionuclide-contaminated soils focused on the detection of plutonium through the measurement of the plutonium daughter product, americium-241 (^{241}Am; Proctor and Hendricks, 1995). Americium-241 can be more readily measured than the alpha-emitting plutonium isotopes because ^{241}Am emits gamma rays.

Immediate post-shot cleanup at each test involved disposing of contaminated debris in a pit at GZ, scraping the surface soil around GZ to a depth of several inches, and placing the soil in the disposal pit or mounding it over the contaminated debris. The mound of contaminated materials was covered with additional soil and compacted and watered (Johnson and Edwards, 1996) and fences were constructed around the contamination at each site. Based on soil survey data collected during 1973, a second fence was constructed at the approximate limit of 40 picocurie per gram (pCi/g) of plutonium in soil (Duncan *et al.*, 2000).

Aerial surveys of Operation Roller Coaster contamination areas were conducted in 1977 (EG&G, 1979) and 1993 (Proctor and Hendricks, 1995). These surveys used gamma detectors to identify ^{241}Am. Based on the 1977 survey, the total area of diffuse plutonium for all Operation Roller Coaster sites was estimated to be approximately 4,900 acres (Sandia, 2014). The 1993 survey estimated the maximum concentration at the Clean Slate I GZ to be between 200 and 400 pCi/g. At Clean Slate II and III, the maximum concentrations at GZ were reported to be in excess of 2,000 pCi/g. Contamination was reported outside the outer perimeter fence at all three Clean Slate sites. At Clean Slate III, plutonium concentration outside of the fence did not exceed 200 pCi/g. However, the concentrations reported outside the fences at Clean Slate I and II were greater than 200 pCi/g but less than 400 pCi/g (Proctor and Hendricks, 1995).

Soil contamination at Clean Slate I was remediated in 1997 so that the concentration of transuranics was less than or equal to 400 pCi/g (SNL, 2012). Clean Slate II and III have not been remediated.

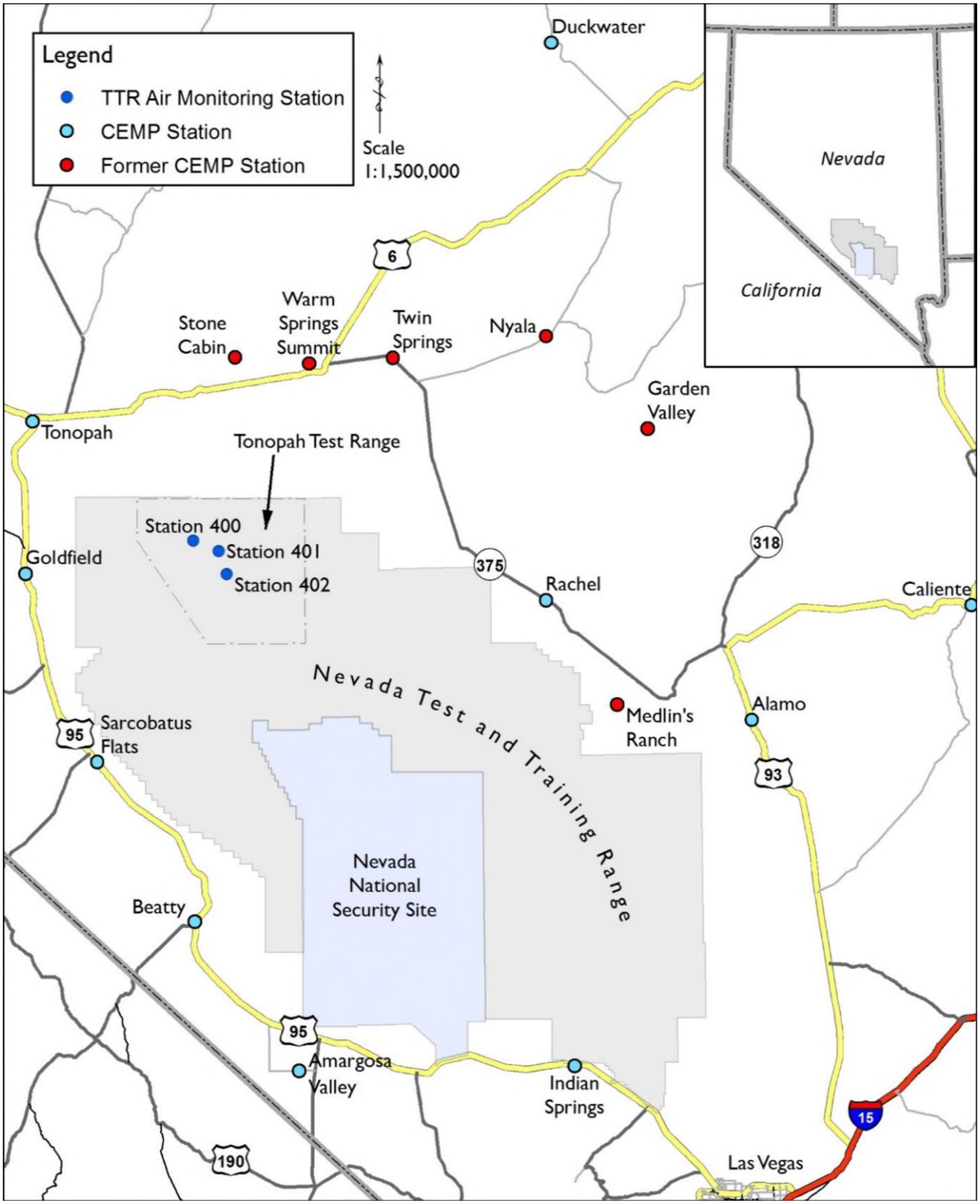

Figure 1. Location of monitoring stations at the Tonopah Test Range (TTR) in the north end of the Nevada Test and Training Range in southern Nevada. Also shown are current and former Community Environmental Monitoring stations (CEMP) for which monitoring data are available.

Figure 2. The TTR environmental monitoring stations are located on the south side of the Sandia National Laboratory compound (Station 400) and the north ends of the Clean Slate I (Station 402) and III (Station 401) contamination areas.

In 2008, at the request of the DOE National Nuclear Security Administration, Nevada Field Office (NNSA/NFO), the Desert Research Institute (DRI) constructed and deployed two portable environmental monitoring stations at the TTR as part of the Environmental Restoration Project, Soils Activity. A third station was deployed in 2011. Desert Research Institute has operated these stations continuously since installation. The primary objective of the monitoring stations is to evaluate whether there is wind transport of radiological contaminants, specifically plutonium, from the Soils Corrective Action Units (CAUs) associated with Operation Roller Coaster and if so, under what conditions such transport occurs. Instrumentation currently in use is intended to quantify radiological constituents in the air to a height of six to eight feet above the local ground surface. The objective of this annual report is to document the operation of the TTR monitoring stations during calendar year (CY) 2015, present the data collected, interpret the results in the context of the monitoring objectives, and provide recommendations as needed.

MONITORING STATION LOCATIONS AND CAPABILIITIES

TTR monitoring stations 400 and 401 were installed in May and June 2008, respectively. Station 402 was installed in May 2011. Wind direction, access, and power availability were key considerations in selecting the specific monitoring station locations. Wind data for the Tonopah Airport (Engelbrecht *et al.*, 2008) indicated that the predominant wind directions in the area were from the northwest and south-southeast. Wind direction data collected from the TTR monitoring stations substantiate the assessment of Engelbrecht *et al.* (2008).

Station 400 is located at the Sandia National Laboratories (SNL) Range Operations Center (ROC). Station coordinates are given in Table 1. The ROC, adjacent TTR airfield, and surrounding work area are downwind of the Clean Slate contamination sites when winds are out of the south-southeast. At a distance of eight to nine kilometers (five to six miles), these facilities are the closest, regularly manned work locations to the Clean Slate contamination sites. Therefore, Station 400 facilitates the characterization of radiological conditions in the TTR work areas that may result from wind transport of radionuclide-contaminated soils at the Clean Slate sites and provides data to compare radiological conditions at the ROC with conditions at the Clean Slate sites. Station 400 was originally located just north of the center of the SNL compound, approximately 145 m (475 ft) west-northwest of the ROC. In the summer of 2012, the station was moved approximately 200 m (650 ft) to the southeast at the request of SNL. In the new location, Station 400 is approximately 90 m (300 ft) south of the ROC near the southeast corner of the SNL compound (Figure 2). Sandia National Laboratories provides line power to operate the equipment at Station 400, which consists of a meteorological tower and air sampling equipment installed on a 2.1 m x 4.3 m (7 ft x 14 ft) trailer (Figure 3).

Table 1. Location coordinates for the TTR air monitoring stations.

Station	Latitude	Longitude
Station 400 – original	37° 47’ 15” N	116° 45’ 26” W
Station 400 – current	37° 47’ 10” N	116° 45’ 21” W
Station 401	37° 45’ 39” N	116° 40’ 58” W
Station 402	37° 42’ 33” N	116° 39’ 32” W

Figure 3. Station 400 is a trailer-mounted radiological and meteorological measurement system located near the Range Operations Center (ROC) in the Sandia National Laboratories (SNL) compound on the TTR.

Stations 401 and 402 are located at the demarcation fence on the northwest perimeter of the Clean Slate III and Clean Slate I sites, respectively (Figure 2). These locations were chosen because the monitoring instrumentation is placed in proximity to the contamination sites and on the downwind side of the sites during south-southeast winds, one of the two predominant wind directions through the area. Both Stations 401 and 402 are solar powered with battery backup power and the batteries are recharged by solar panels. Table 1 gives the coordinates for these monitoring stations. At Stations 401 and 402, the air samplers, solar panels, and the batteries used to power the samplers are on trailers. This arrangement requires that the meteorological towers be installed on free-standing tripods that are separate from the trailer (Figures 4 and 5).

Figure 4. The solar powered air sampler, saltation sensor, and meteorological tower (background, center, and foreground, respectively) at Station 401 are located along the north fence that bounds the Clean Slate III contamination area.

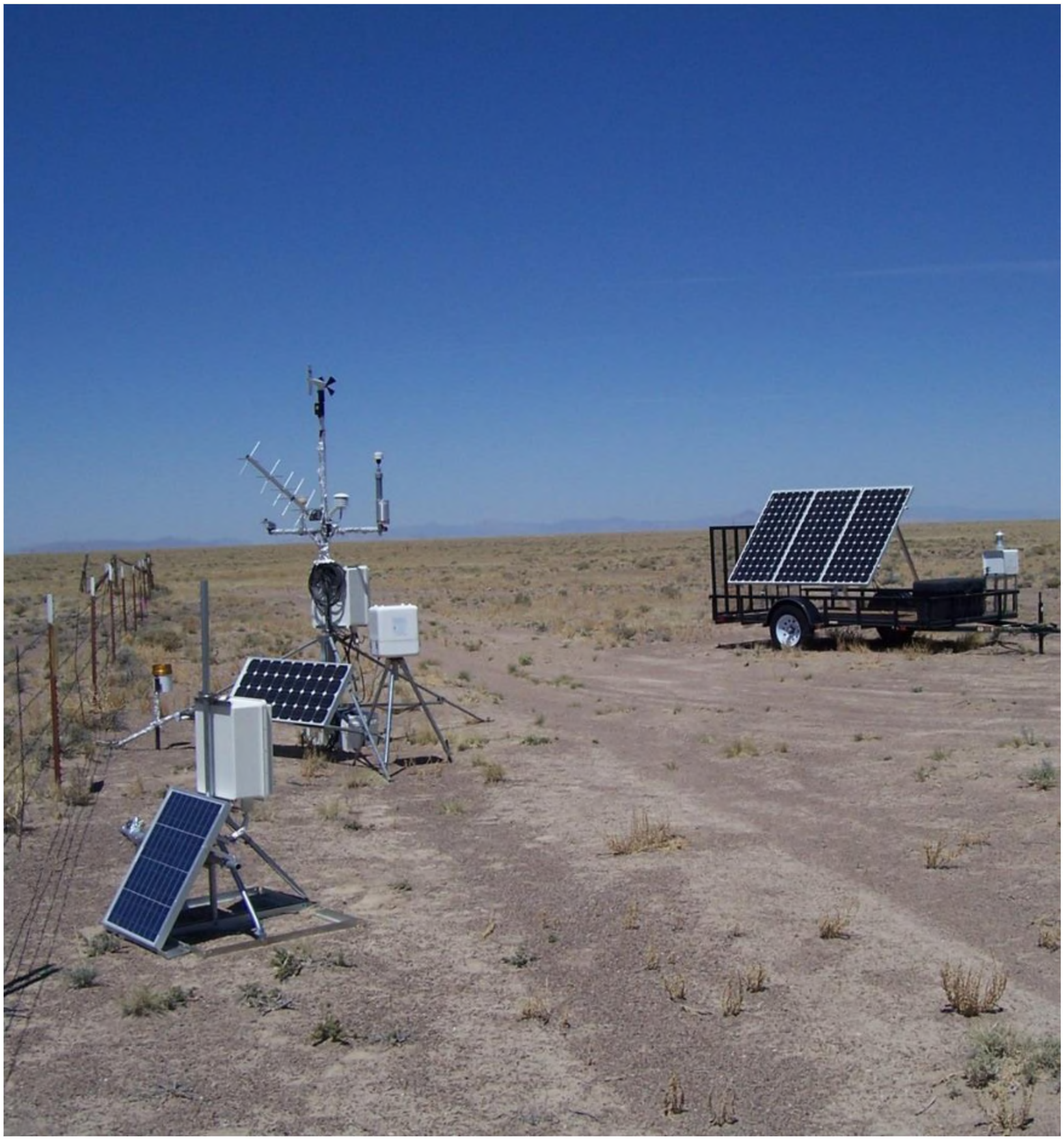

Figure 5. The solar powered air sampler, saltation sensor, and meteorological tower (center right, foreground left, and center left, respectively) at Station 402 are located along the north fence that bounds the Clean Slate I contamination area.

The fundamental design of these stations is similar to that used in the Community Environmental Monitoring Program (CEMP) (NSTec, 2013). The Quality Assurance Program is also patterned after that used by CEMP (Appendix A). The equipment deployed provides data on radiological, meteorological, and environmental conditions. Table 2 lists the parameters measured and the approximate date of the initial data collection at each of the three monitoring stations. Plutonium was the principal radionuclide released into the environment during the Clean Slate experiments. It attaches to small soil particles and may be suspended in the air and transported from the site along with windblown dust. Americium-241, a daughter product of plutonium-241 (^{241}Pu) that releases gamma energy during decay, is much easier to detect than the alpha particle released during plutonium decay. Therefore, two radiological data collection systems are deployed at each of the monitoring stations. Gamma energy is measured using a pressurized ionization chamber (PIC) (Reuter Stokes, Youngstown, Ohio) and airborne particulates are collected for radiological analysis. Continuous flow, low-volume (flow rate is approximately 0.05663 m^3 [2 ft^3] per minute) air samplers (Hi-Q Environmental Products, San Diego, CA) are used to collect airborne particulates.

Glass-fiber filters with a pore size of 0.3 µm and diameter of 10 cm (4 in) are currently in use. Prior to CY2013, Stations 401 and 402 used cellulose-fiber filters with a pore size of 20 µm to 25 µm. The conversion to all glass-fiber filters was made to ensure that the smaller-sized particulates to which plutonium might be attached are collected. Filters are retrieved every two weeks and are delivered to the Radiological Services Laboratory (RSL) at the University of Nevada, Las Vegas, for analyses.

Table 2. Radiological, meteorological, and environmental sensors deployed at the TTR air monitoring stations. The dates refer to the first occurrence of data collection for that parameter at the given station.

Instrument/Measurement	Station 400	Station 401	Station 402
Wind speed	5/27/2008	6/10/2008	5/18/2011
Wind direction	5/27/2008	12/22/2009	5/18/2011
Precipitation	5/27/2008	12/22/2009	5/18/2011
Temperature	5/27/2008	6/10/2008	5/18/2011
Relative humidity	5/27/2008	6/10/2008	5/18/2011
Solar radiation	5/27/2008	na	5/18/2011
Barometric pressure	5/27/2008	na	5/18/2011
Soil temperature	5/27/2008	12/22/2009	5/18/2011
Soil moisture content	5/27/2008	12/22/2009	5/18/2011
Airborne particle size profiler	5/27/2008	6/10/2008	5/18/2011
Airborne particle collector	5/27/2008	7/30/2008	8/23/2011
Saltation sensor	na	8/9/2011	8/9/2011
Gamma radiation PIC	5/27/2008	12/22/2009	12/15/2011
MiniVol™ [1]	5/27/2008	na	na
Data logger	5/27/2008	6/10/2008	5/18/2011
GOES[2] transmitter	5/27/2008	12/22/2009	5/18/2011
BSNE[2] sand traps	na	4/01/2014	4/01/2014

[1] Samples have never been collected from the MiniVol™ collectors.
[2] See text for acronym definition
na = not available.

The total mass of collected dust is submitted for gross alpha, gross beta, and gamma spectroscopy analyses in an effort to assess the magnitude of radionuclides associated with the suspended dust. Gamma spectroscopy is performed to determine if ^{241}Am is present. If ^{241}Am is detected, then alpha spectroscopy is performed to confirm and determine the quantity of plutonium isotopes.

Because plutonium particles tend to attach to small soil particles, wind-suspended dust and rainfall runoff from contaminated soil sites are the likely mechanisms for transporting radiological contaminants beyond the physical and administrative boundaries of each site. The effort reported here focused on possible transport by wind resuspension. Additionally, inhaling plutonium-contaminated dust particles is the most likely mechanism for human exposure. Suspension and transport of contaminated dust is controlled by local meteorological and other environmental conditions, such as wind speed and soil moisture content. Many meteorological parameters influence these conditions. Electronic sensors measure meteorological and other environmental conditions every three seconds. These measurements are averaged or totaled, as appropriate, and stored in the on-site data logger every 10 minutes. The maximum and minimum value of each parameter are also saved on the data logger. These values are used to evaluate data quality. The data loggers are downloaded during site visits every two weeks. To assess instrument performance and provide rapid updates of observations, hourly averages of the 10-minute data are transmitted to the Western Regional Climate Center (WRCC) via the Geostationary Operational Environmental Satellite (GOES) system. At the WRCC, data are quality checked and archived for interpretation. A gap in automatic data collection occurred at Station 402 during the first part of August 2015 because a battery failure at the station damaged the charge controller and replacement parts needed to be obtained.

In addition to the automatic sensors, one MiniVol™ (Air Metrics, Springfield, Oregon) is deployed at Station 400. This sampler is intended to be run in the event of a nearby wildfire or during extreme dust storms because it is set up to facilitate analyses that distinguish organic and inorganic constituents. The MiniVol™ is a manually activated, low-volume air sampler equipped with Teflon™ filters. No events caused the MiniVol™ to be activated in 2015, so no data were collected from this instrument.

BSNE SAND TRAP INSTALLATION

On April 1, 2014, DRI installed Big Spring Number Eight (BSNE; Custom Products and Consulting LLC, Big Spring, Texas) samplers to monitor soil transported by saltation at Clean Slate I and III. The BSNEs are wind-aspirated samplers that collect sand that enters the opening (Figure 6). The inlet height is set at 15 cm (6 in) to collect the near-ground erodible soil material transported by saltation. Two collectors are installed at each mounting rod (Figure 7). One of the collectors is pointed toward the contaminated area at 160 degrees from north to collect material likely to have been transported from the Clean Slate site under the influence of south-southwesterly winds. The other collector is pointed in the opposite direction and is used to collect the material moving toward the Clean Slate sites. This physical setup and orientation allows the net movement of soil material from the Clean Slate sites to be determined.

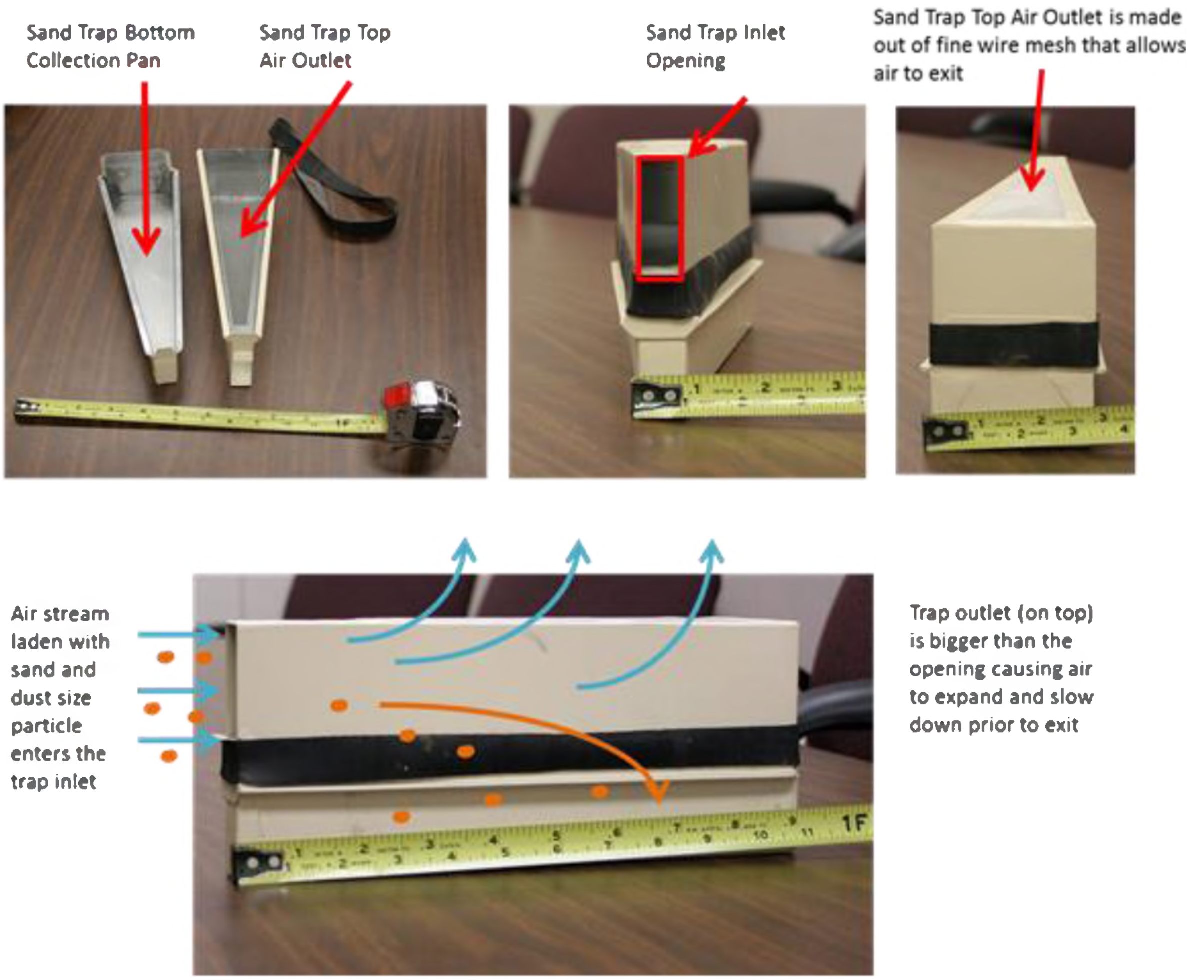

Figure 6. Sand particles are carried into the BSNE sand trap by fast-moving air. As the air slows down, momentum is lost and the particles settle on the bottom of the collection pan. Dust particles may be small enough to be carried out through the wire mesh at the top of the trap by air.

Figure 7. Northeast view at Station 401. In the foreground is one of three BSNE sand trap installations at TTR Clean Slate III. The Clean Slate III boundary fence is to the right. Behind the sand trap is the saltation sensor and meteorological station with additional sand traps located along the fence line.

Three replicate BSNE samplers with two collectors each were installed at both Clean Slate I and Clean Slate III (Figures 8 and 9) along the fence line. The information collected will help determine if contaminated material reaches the fence line and the amount of net soil migration over time. These samplers are passive and field operators check the sampler mass loading during the biweekly site visits. Desert Research Institute has developed a procedure in conjunction with other DOE contractors to collect and analyze the soil trapped in the BSNEs. The initial expectation was that a three- to four-month collection period would be used to better understand seasonal and geographic trends. However, it was nearly a year before there was enough material in the traps for laboratory analysis.

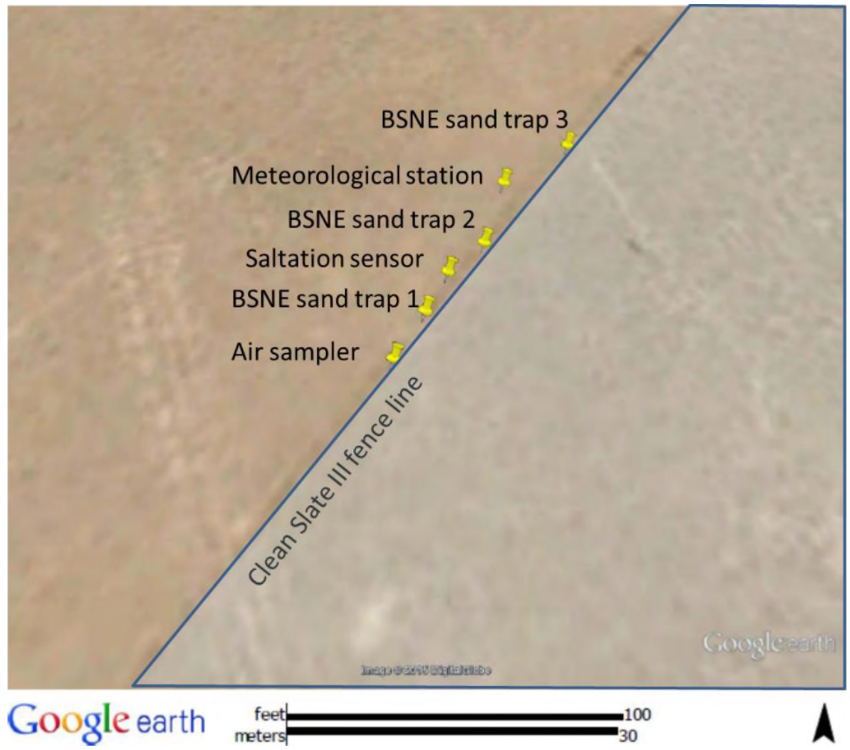

Figure 8. Equipment locations along the fence line at TTR Clean Slate III, Station 401.

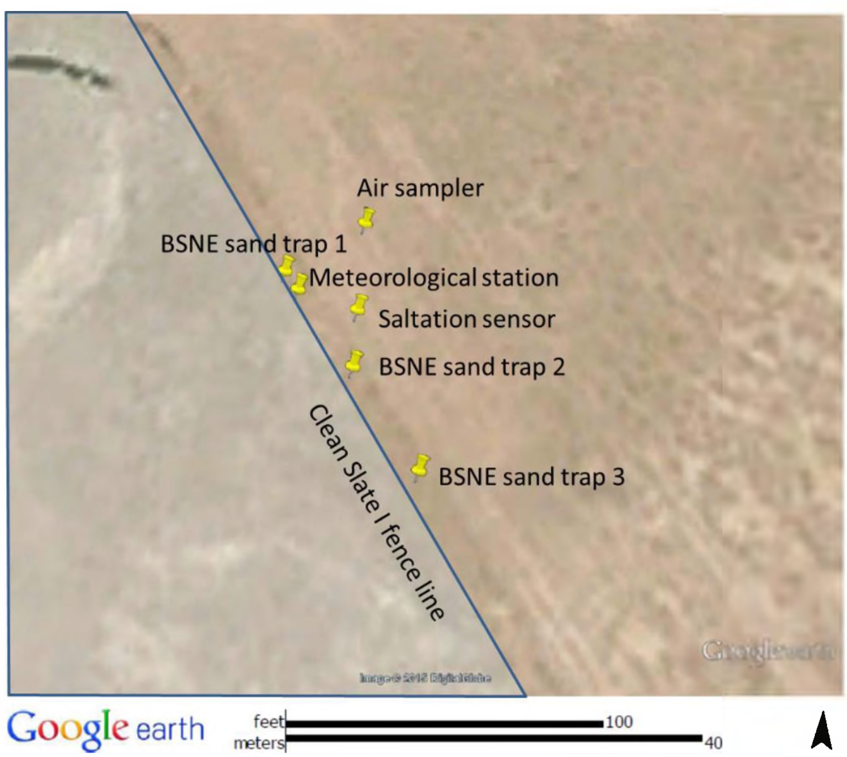

Figure 9. Equipment locations along the fence line at TTR Clean Slate I, Station 402.

WEATHER CONDITIONS AND OTHER ENVIRONMENTAL PARAMETERS

Summary tables of the meteorological data recorded at the stations are presented in Appendix B and daily average meteorological and environmental data are plotted in Appendix C. These data are summarized and discussed below. Air temperature trends recorded during the year at Stations 400, 401, and 402 between January 1, 2015, and December 31, 2015, are shown in Figures 10 through 12. The three traces shown in the figures depict the maximum, average, and minimum daily temperature based on hourly average measurements. The average air temperature during CY2015 for Station 400 was 12.4 degrees Celsius (°C), or 54.4 degrees Fahrenheit (°F). The highest air temperature of 36.4 °C (97.6 °F) was recorded in June and the lowest air temperature of -14.7 °C (5.5 °F) was recorded in December. The highest average monthly air temperature of 24.1 °C (75.3 °F) was recorded in August and the lowest average monthly air temperature of -1.1 °C (30.05 °F) was recorded in December. Air temperature at Stations 401 and 402 follow a very similar trend as Station 400 (Figure 13). The maximum observed air temperature at Station 401 was 39.5 °C (103.1 °F) in June and the lowest air temperature was -17.4 °C (0.6 °F) in December. The average annual air temperature at Station 401 was 13.4 °C (56.2 °F). The maximum observed air temperature at Station 402 was 37.7 °C (99.8 °F) in June and the lowest air temperature was -21.5 °C (-6.7 °F) in December. The average annual air temperature at Station 402 was 11.6 °C (52.9 °F). It is important to note that small differences in air temperature readings may be because of an individual temperature sensor bias. The air temperature sensor used at the monitoring stations is a Campbell CS 215 (https://www.campbellsci.com/cs215-l) with a reported accuracy of ±0.5 °C between the 5 and 40 °C (40 to 105 °F) temperature range.

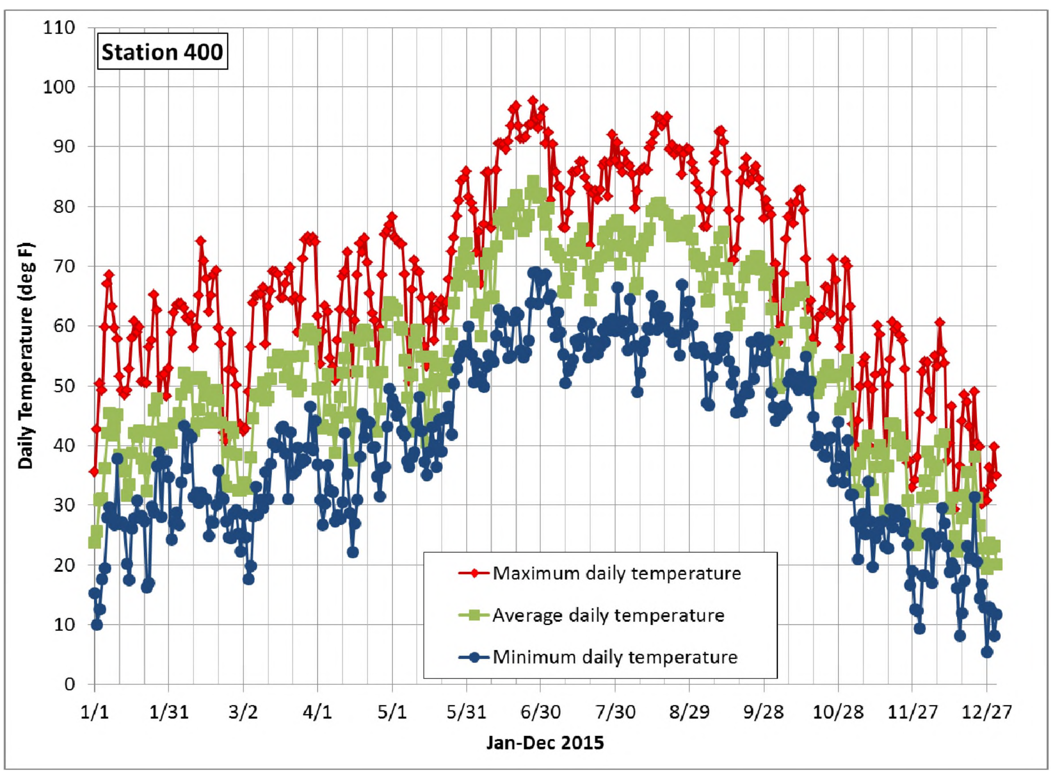

Figure 10. Ambient air temperature for Station 400 for CY2015.

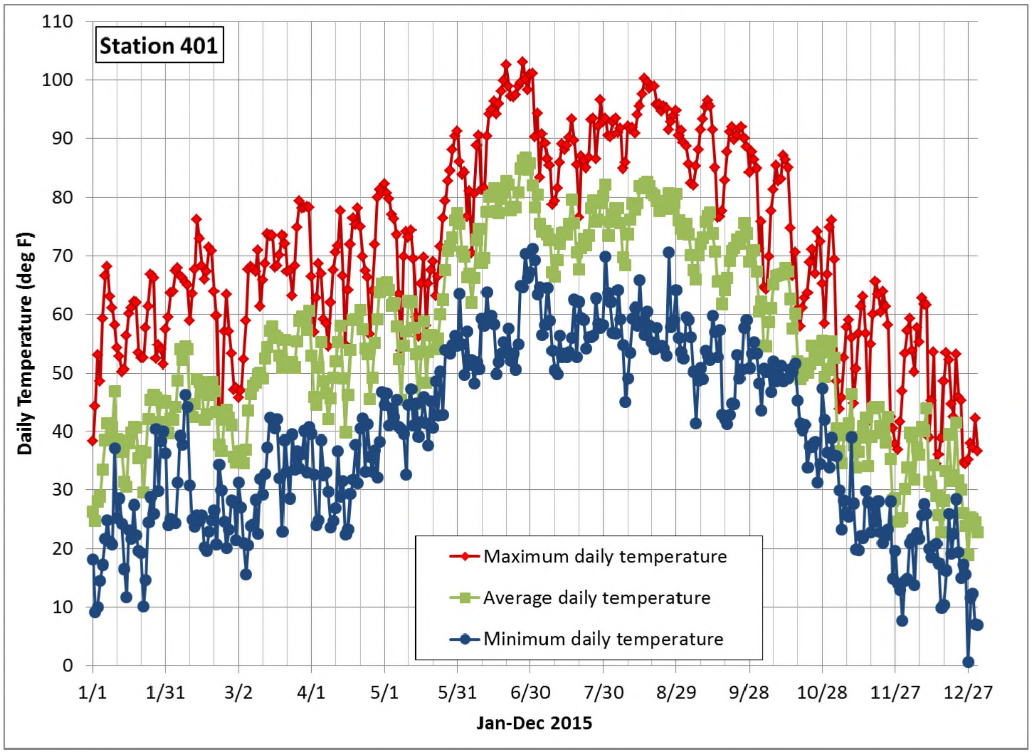

Figure 11. Ambient air temperature for Station 401 for CY2015.

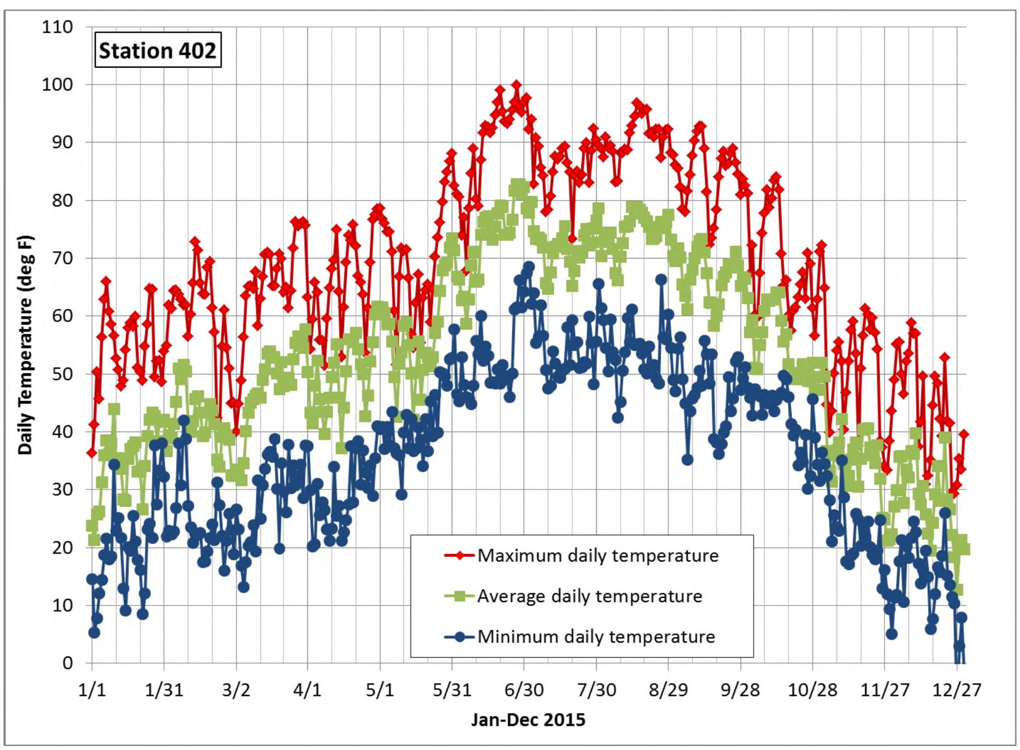

Figure 12. Ambient air temperature for Station 402 for CY2015. The data gap in August was because of equipment failure at the station.

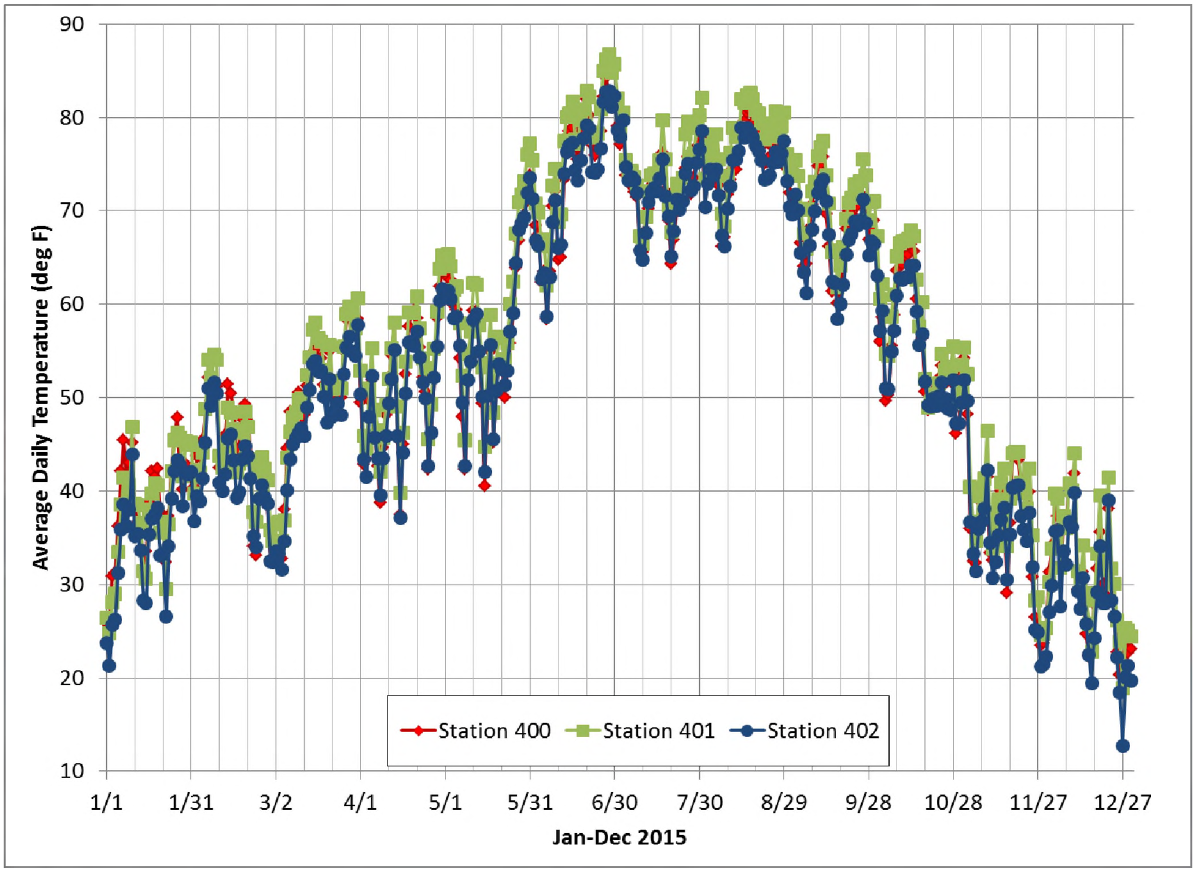

Figure 13. Average ambient air temperature for Stations 400, 401, and 402 for CY2015.

The daily average soil temperature for all three TTR stations is shown in Figure 14. Soil temperature is measured using temperature probes made of thermocouple wire that have been buried at a depth of 10 to 13 cm (4 to 5 in). Generally there are minor differences in soil temperature readings between the stations. These minor differences may be explained in part by differences in local soil thermal conductivity, soil moisture, vegetation cover, and variations in probe burial depth. Station 400 generally indicates higher soil temperature compared with Stations 401 and 402. The gravel ground cover at Station 400 loses moisture more rapidly than the fine-grained soils at Stations 401 and 402. The absence of soil moisture at Station 400 would permit a stronger response of soil temperature to air temperature compared with the responses observed at Stations 401 and 402 where soil moisture is more readily retained. The data from Station 401 (Figure 15) show the close relationship between soil temperature and air temperature.

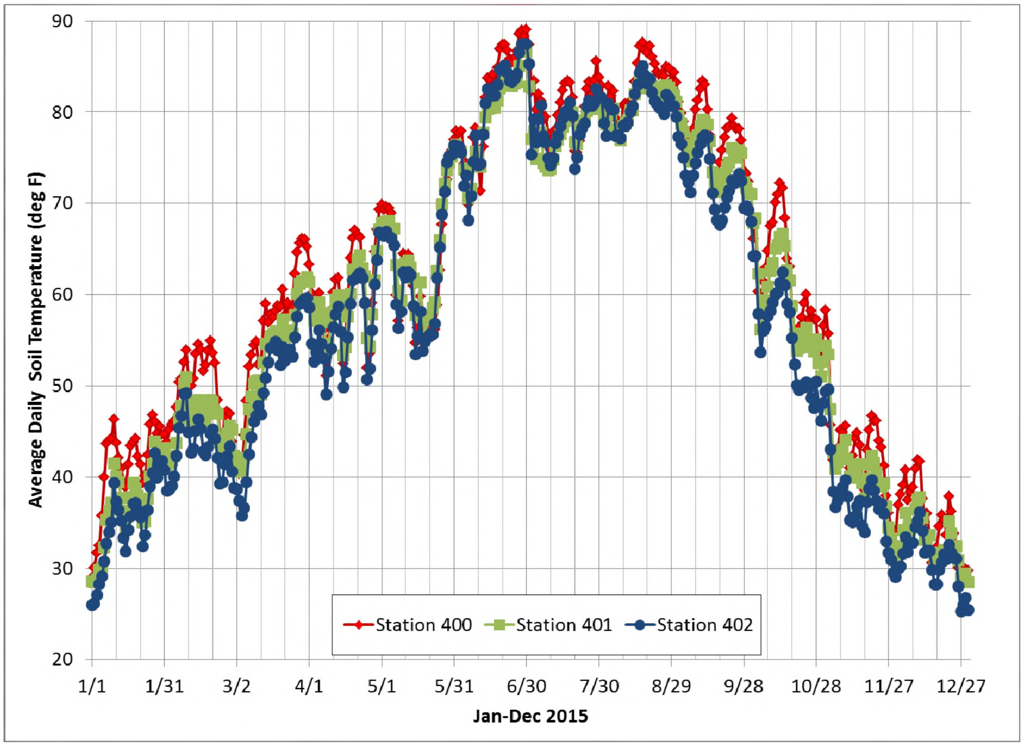

Figure 14. Average ambient soil temperature for Stations 400, 401, and 402 for CY2015.

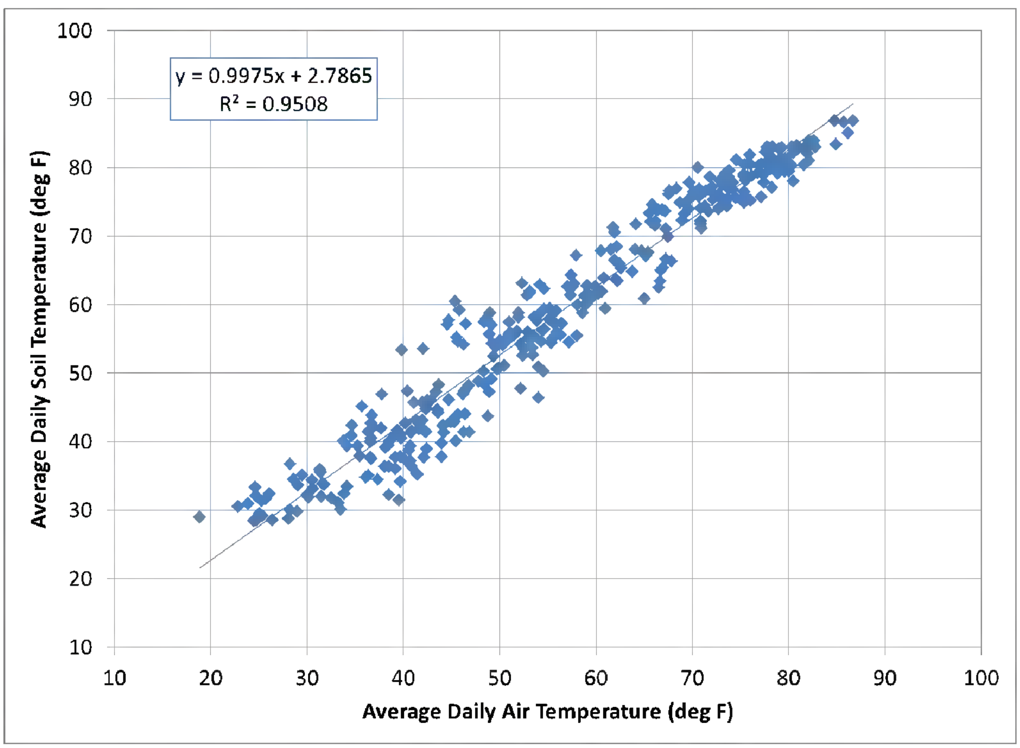

Figure 15. Comparison of average air and average soil temperatures by regression illustrates the close relationship between the two parameters at Station 401.

Total daily precipitation for Stations 400, 401, and 402 in the period between January 1, 2015, and December 31, 2015, is shown in Figure 16. The total cumulative precipitation for Stations 400, 401, and 402 for the period between January 1, 2015, and December 31, 2015, is shown in Figure 17. Precipitation for CY2015 totaled 122.4 mm (4.82 in) for Station 400 and 162.3 mm (6.39 in) for Station 401 and 143.3 mm (5.64 in) for Station 402. The closeness of these totals indicates that major precipitation events were widespread enough to be recorded by all three stations. The maximum total daily precipitation occurred on October 4, 2015, with Stations 400, 401, and 402 receiving 29.5 mm (1.16 in), 33.2 mm (1.31 in), and 28.7 mm (1.13 in), respectively, on that day. The maximum total daily precipitation at Station 401 on October 4, 2015 approximates a 5-year, 24-hour storm per http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nv, accessed July 18, 2016. The other major precipitation events occurred May 18, July 1, October 18, and November 3 of 2015. The maximum monthly precipitation occurred in October during which Stations 400, 401, and 402 received 44.7, 53.6, and 62.5 mm (1.76, 2.11, and 2.46 in) of rain, respectively. This is somewhat different from the previous three years of monitoring in which most of the rain was delivered between the end of July and middle September, when the influence of monsoon precipitation is strongest.

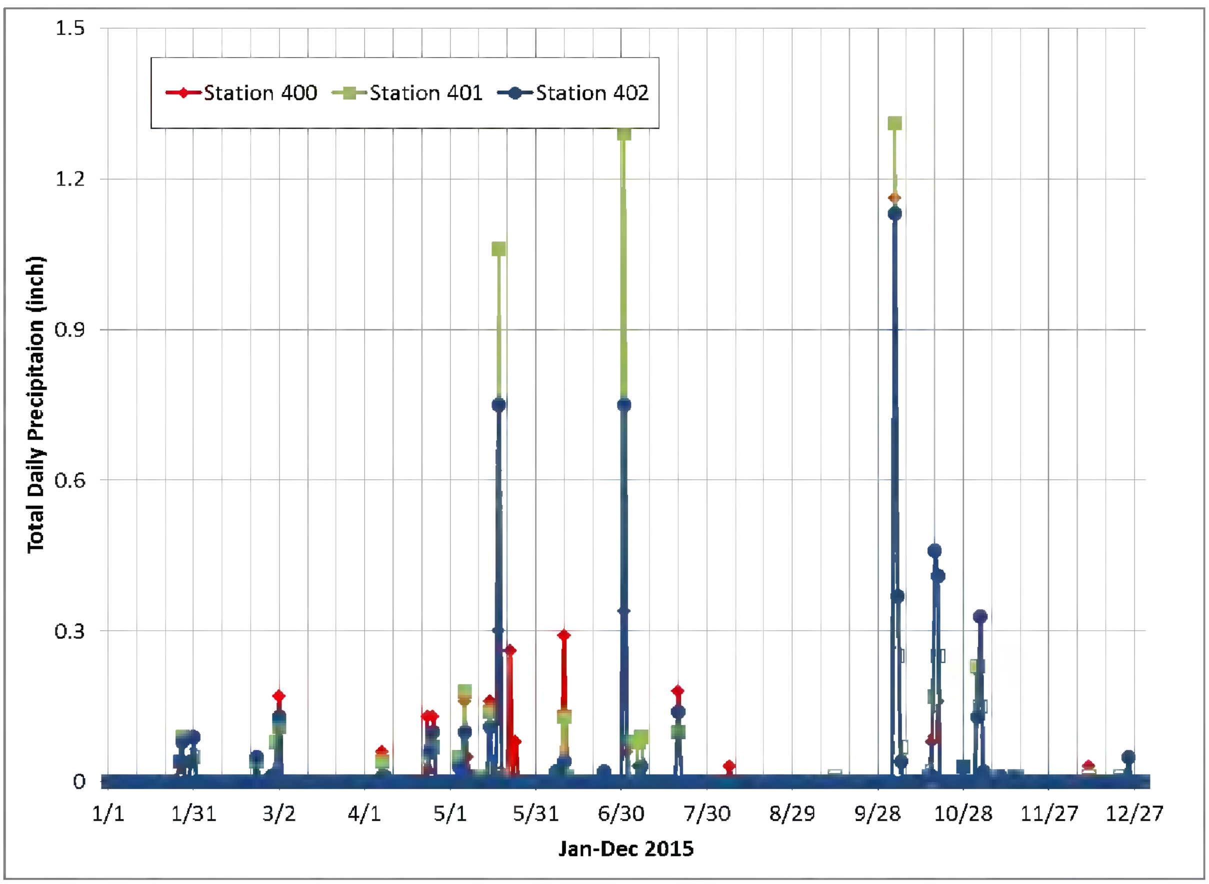

Figure 16. Total daily precipitation for Stations 400, 401, and 402 for CY2015.

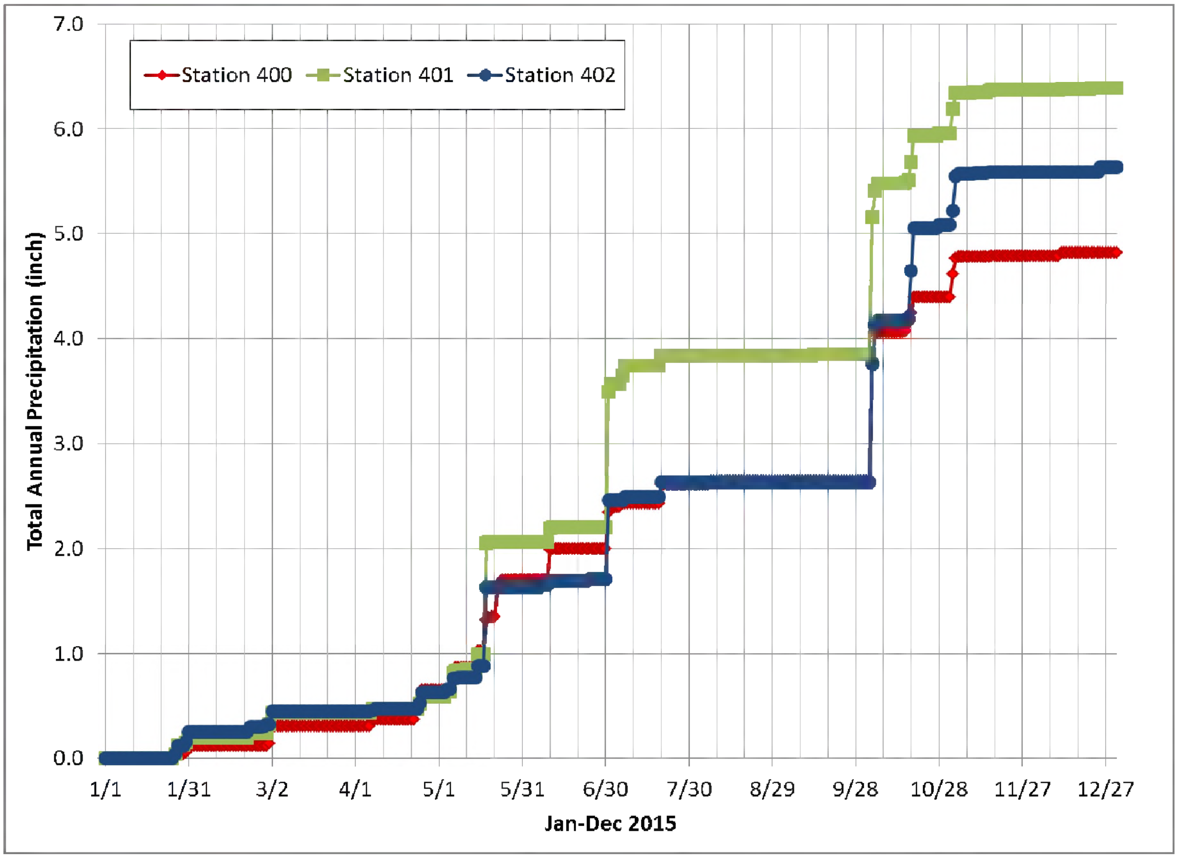

Figure 17. Cumulative precipitation for Stations 400, 401, and 402 for CY2015.

Total annual precipitation for each of the three stations during CY2015 averages 142.7 mm (5.62 in), which is slightly over the historic average annual precipitation of 129.03 mm (5.08 in) measured at the Tonopah Airport from 1954 through 2015 (www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv8170, accessed April 20, 2015). The CY2015 average total annual precipitation is approximately equal to that measured at the stations in CY2014 (137.9 mm, 5.43 in). Because non-heated rain gages are used at the three stations, snowfall may be underestimated if the gages froze or if snow was blown or sublimated out of the gage before it melted. However, because the majority of the precipitation was during warmer months, snow losses should be small for CY2015.

The water content of the top layer of soil is most relevant to soil migration by high winds. Sufficiently high soil-moisture content is expected to diminish the soil material available for wind transport because moisture helps bind the soil particles together. Soil volumetric water content (VWC) was monitored at all three stations in the top 5 cm (2 in) of soil using time domain reflectometry (TDR) probes. The TDR probes provide an estimate of soil water content based on the direct measurement of electrical soil conductivity. The TDR is a good indicator of relative changes in soil water content associated with precipitation and snowmelt events and drying periods. Absolute values of VWC are less meaningful without in-situ calibration. Even then, it can be difficult to relate the local TDR measurement to areal averages of soil moisture. Figure 18 shows the daily average VWC of the topsoil layer at

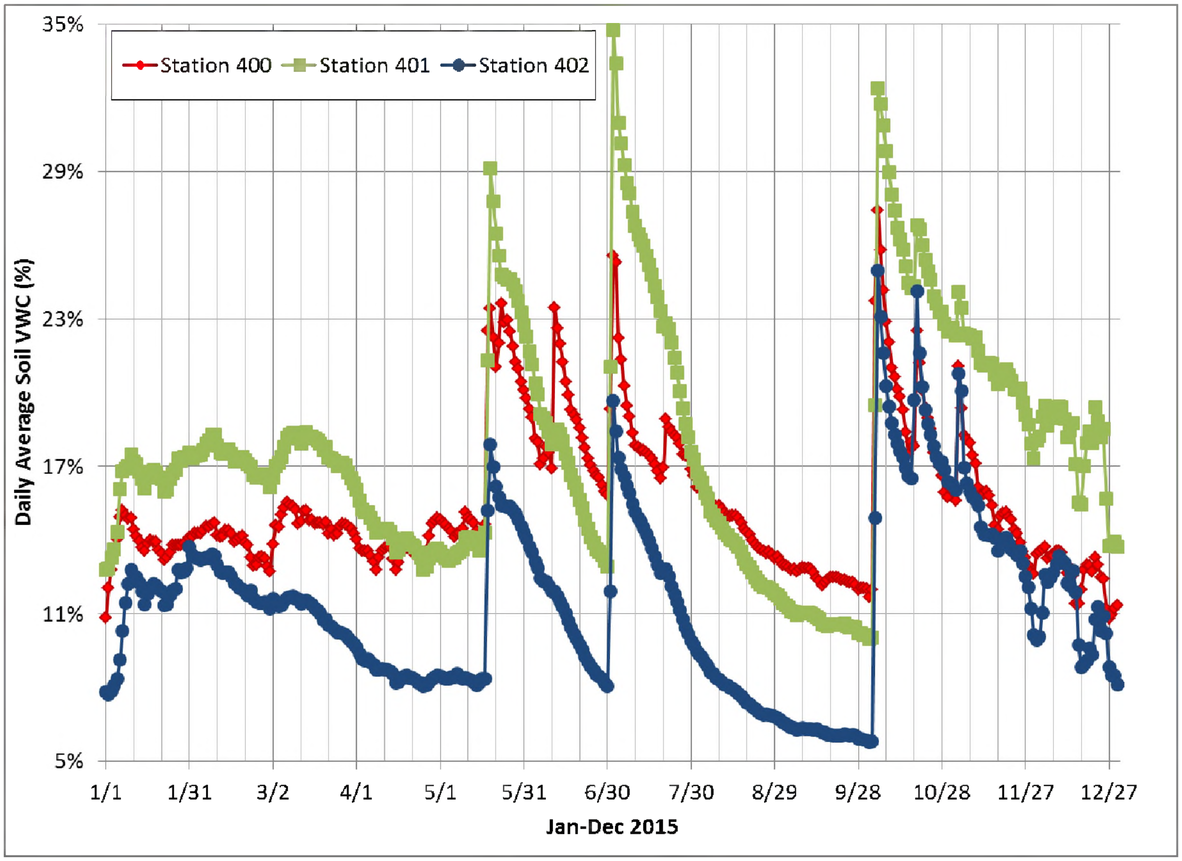

Figure 18. Soil volumetric water content for Stations 400, 401, and 402 for CY2015.

Stations 400, 401, and 402 for the period between January 1, 2015, and December 31, 2015. Increases in soil VWC coincide with precipitation events and subsequent decreases in VWC correspond to drying periods. Soils had the lowest absolute VWC in May and September 2015 and the highest at the beginning of July and October 2015 following a series of rain events.

Figure 19 shows the daily average relative humidity for all stations for the monitoring period between January 1, 2015, and December 31, 2015. During precipitation events, the relative humidity increases near to the saturation value of 100 percent. Relative humidity at the TTR monitoring stations for a typical year is lowest between April and July when precipitation events are rare and air temperature is high. The lowest monthly average relative humidity in 2015 was measured in June and was 22.5 percent, 27.8 percent, and 23.5 percent for Stations 400, 401, and 402, respectively. The highest monthly average relative humidity in 2015 was measured in October and was 56.5 percent, 65.3 percent, and 65.1 percent for Stations 400, 401, and 402, respectively.

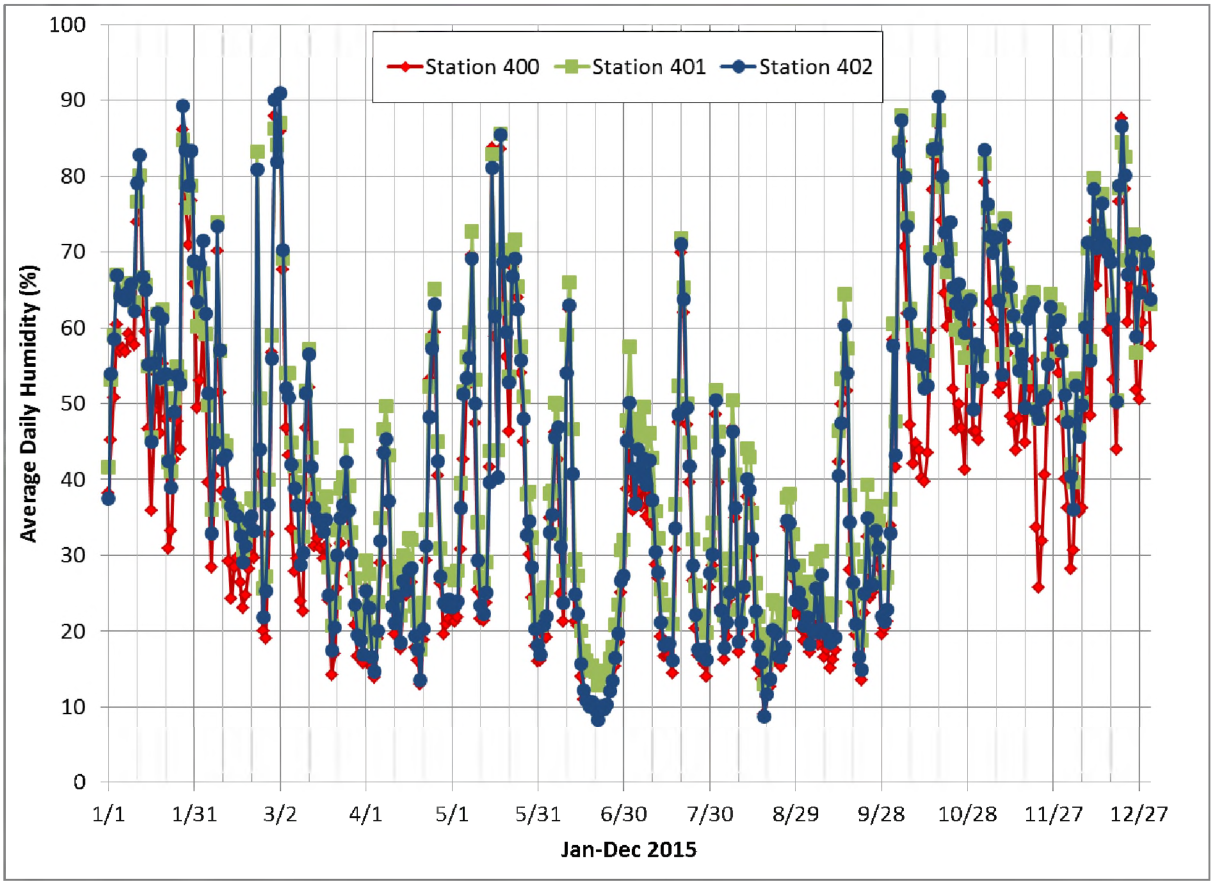

Figure 19. Average daily relative humidity for Stations 400, 401, and 402 for CY2015.

Because wind is an expected major pathway for soil transport at the Clean Slate sites, both wind speed and wind direction are collected at all TTR monitoring stations. Wind rose diagrams (Figures 20 and 21) have been developed for all three stations for CY2015. Wind roses classify wind direction into sixteen "pie slices" that occupy 22.5 degrees and the different colors indicate different wind speed classes. The frequency of each wind speed class and wind direction is indicated by the length of each "pie slice" band. In Figure 20, each station has two wind roses that cover the same time period. The one on the left shows all wind speeds and their contribution to the overall wind rose and the one on the right shows only winds above 24 km/hr (15 mph).

In general, winds above 24 km/hr (15 mph) result in elevated PM_{10} (particulate matter of aerodynamic diameter of less than 10 micrometers) concentrations in the air. The PM_{10} concentration is an indicator of small particles that are suspended in the air and can be easily inhaled. It is estimated from the particle size distribution as measured by the Met One (Model 212) Particle Size Profiler, an instrument that uses the optical properties of particles to infer size and concentration. As seen in Figure 20, the most prevalent winds are from the south or northwest, especially for wind speeds above 24 km/hr (15 mph).

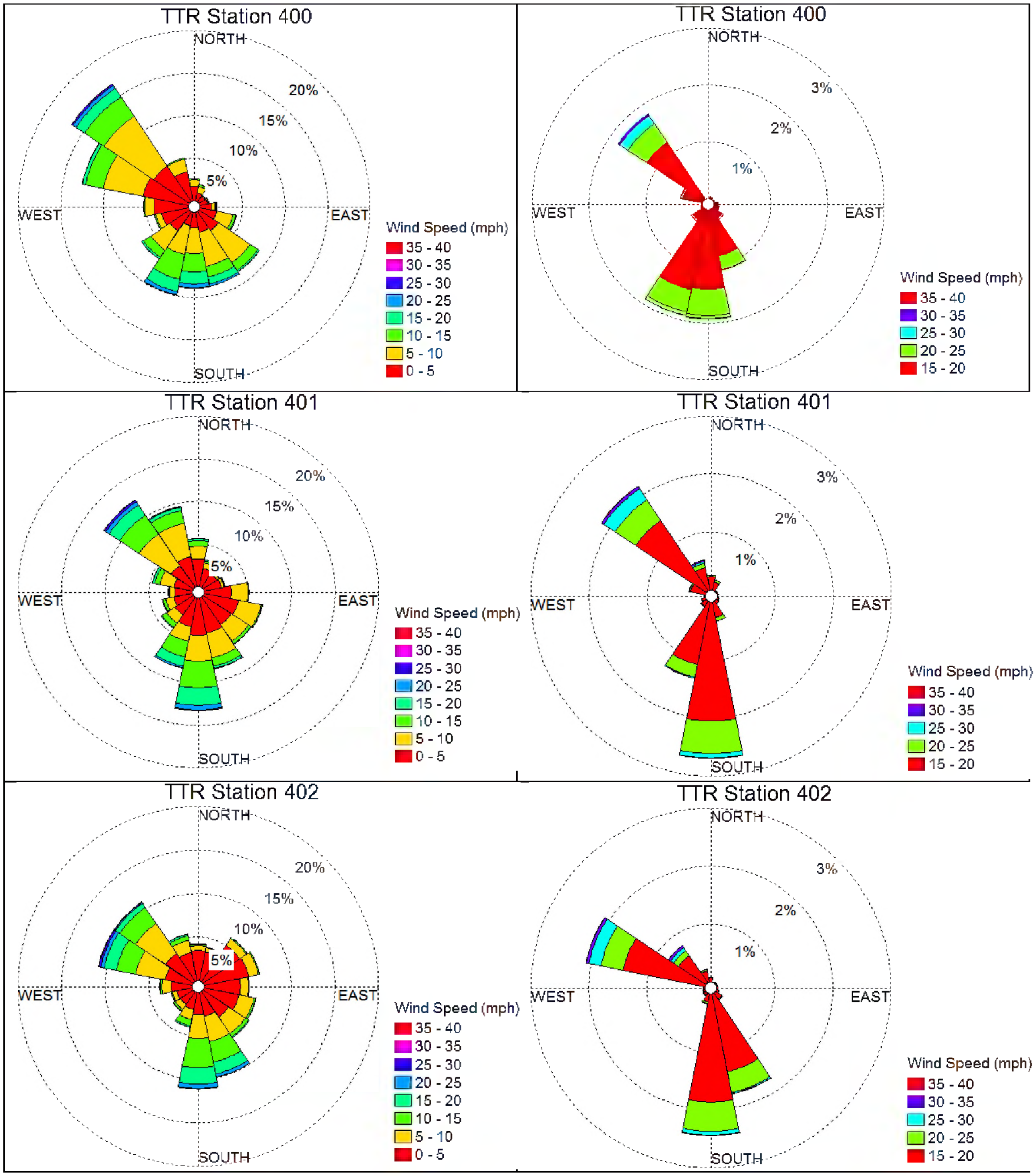

Figure 20. Annual wind roses for Stations 400, 401, and 402 for CY2015. Left panel: all winds. Right panel: winds greater than 24 km/hr (15 mph).

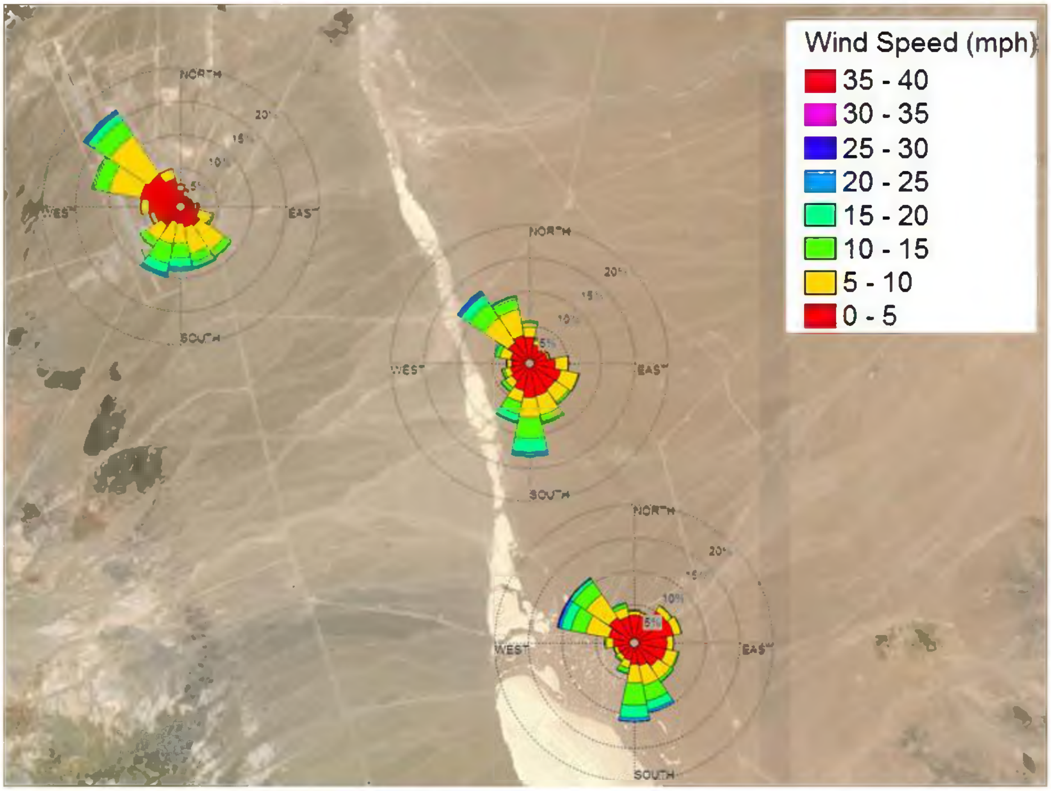

Figure 21. Annual wind rose diagrams for the TTR stations shown in map view.

The geographic context of the wind can be seen in Figure 21. Winds mostly blow out of southerly and northwesterly directions with only very slow winds blowing fairly infrequently out of the east. The wind roses on the right that show only winds above 24 km/hr (15 mph) highlight this fact because virtually only southerly and northwesterly winds are available.

Figure 22 illustrates the time series of average daily winds. The annual average winds during CY2015 were 11.6, 10.7, and 10.3 km/hr (7.18, 6.66, and 6.41 mph) at Stations 400, 401, and 402 respectively. The maximum average monthly winds were recorded in April and May and were 13.6, 13.5, and 12.9 km/hr (8.43, 8.37, and 8.04 mph) at stations 400, 401, and 402, respectively. Maximum daily winds were recorded on February 6, April 14, November 16, and December 14 of 2015. The highest 10-minute interval sustained winds were recorded in April and were 56.8, 60.6, and 59.0 km/hr (35.3, 37.7, and 36.7 mph) at Stations 400, 401, and 402 respectively. The highest three second interval wind gusts were also recorded in April and were 86.7, 83.1, and 82.3 km/hr (53.9, 51.7, and 51.2 mph) at Stations 400, 401, and 402 respectively.

The barometric pressure (atmospheric pressure) trends for Stations 400 and 402 (Station 401 is not equipped with the barometric pressure sensor) are shown in Figure 23. The fluctuations in barometric pressure can provide an indicator of the passage of weather fronts that can often cause high winds.

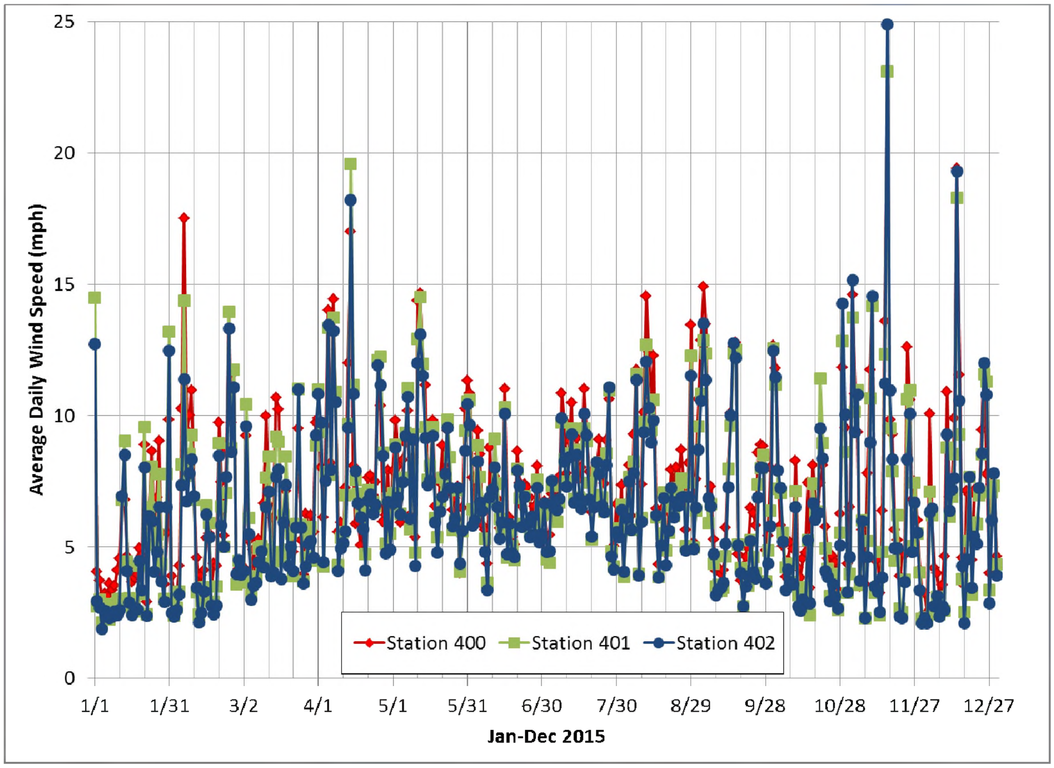

Figure 22. Average daily wind speed for Stations 400, 401, and 402 for CY2015.

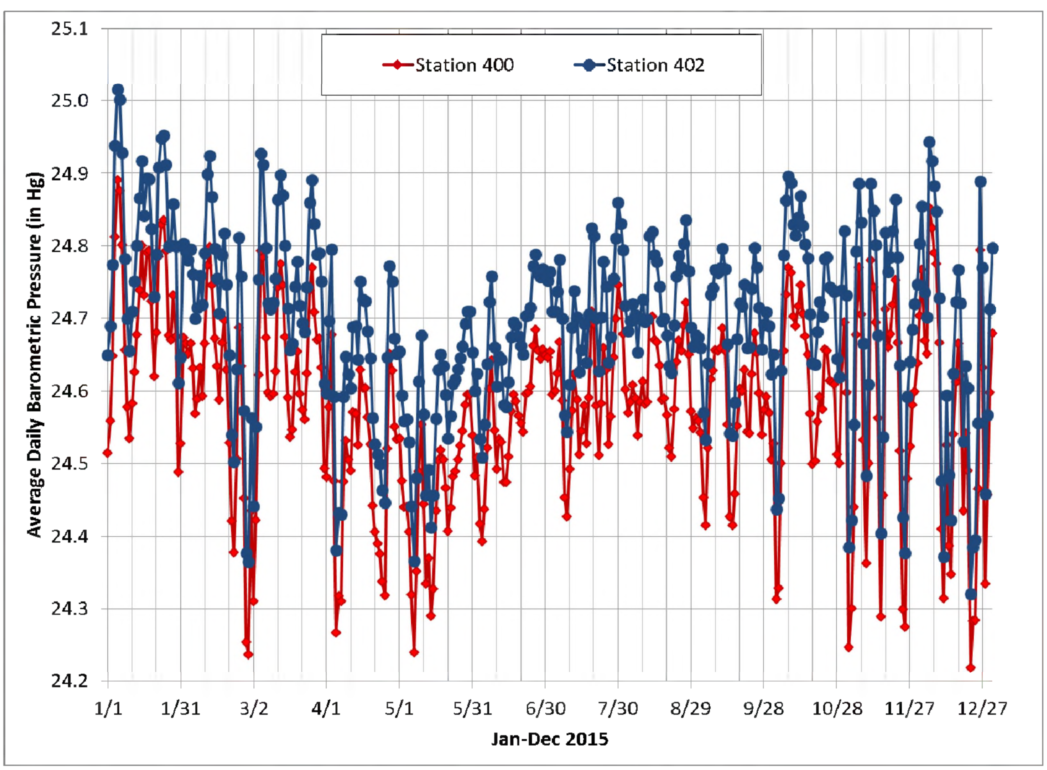

Figure 23. Average daily barometric pressure (BP) for Stations 400, and 402 for CY2015. Station 401 does not have a barometer.

RADIOLOGICAL ASSESSMENT OF AIRBORNE PARTICULATES

Airborne dust particles are collected continuously using Hi-Q™ samplers located at each of the TTR air monitoring stations. A glass-fiber filter (diameter: 10 cm [4 in]; pore size: 0.3 µm) was used at all stations during CY2015. Prior to CY2015, cellulose-fiber filters (diameter: 10 cm [4 in]; pore size: 20 µm to 25 µm) were used at Stations 401 and 402. A cellulose-fiber filter was also used for a duplicate air sampler installed at Station 400 and operated from May 2013 through May 2015 to compare filter performance and related analytical results. Previous monitoring reports (Mizell *et al.*, 2015) observe that gross alpha and gross beta measurements are significantly lower for samples collected with cellulose-fiber filters compared with glass-fiber filters. This is attributed to the finer pore size of the glass-fiber filter, which captures more particles.

The Hi-Q™ air sampling equipment draws ambient air through the filters at a rate of approximately 56.6 L/m (2 cfm) and is designed to maintain the same flow rate as dust is collected on the filter. The total volume of air passed through the filter and the total hours of operation are recorded when filters are recovered from the monitoring stations and new filters are deployed every two weeks. Filters are weighed before and after deployment to determine the mass of particulates collected. Sample filters are accumulated and periodically submitted to the RSL at the University of Nevada, Las Vegas, for gross alpha, gross beta, and gamma spectroscopy assessment. The gross alpha and gross beta observations for CY2015 are summarized below in Tables 3 and 4, respectively.

Table 3. Gross alpha results for TTR sampling stations 2015.

Sampling Location	Number of Samples	Concentration (x 10^{-15} µCi/mL [3.7 x 10^{-5} Becquerel (Bq)/m^3])			
		Mean	Standard Deviation	Minimum	Maximum
Station 400(G)	26	1.22	0.50	0.60	2.90
Station 401(G)	26	1.08	0.51	0.35	2.31
Station 402(G)	25	1.30	0.45	0.51	2.19

NOTES: Bq = Becquerel; m^3 = cubic meter; µCi/ml = microcurie per milliliter; TTR = Tonopah Test Range; (G) = glass-fiber filter; glass-fiber filters retain particulates greater than 0.3 µm.

Table 4. Gross beta results for TTR sampling stations 2015.

Sampling Location	Number of Samples	Concentration (x 10^{-14} µCi/mL [3.7 x 10^{-4} Becquerel (Bq)/m^3])			
		Mean	Standard Deviation	Minimum	Maximum
Station 400(G)	26	1.72	0.38	1.19	2.77
Station 401(G)	26	1.49	0.37	0.83	2.26
Station 402(G)	25	2.01	0.48	1.30	3.21

NOTES: Bq = Becquerel; m^3 = cubic meter; µCi/ml = microcurie per milliliter; TTR = Tonopah Test Range; (G) = glass-fiber filter; glass-fiber filters retain particulates greater than 0.3 µm.

Filters collected during CY2015 were deployed between December 23, 2014, and December 23, 2015. This generated 26 air particulate filter samples for Stations 400 and 401. Only 25 particulate samples were collected from Station 402 because of the failure of the air sampling unit in July 2015. The mean annual gross alpha activity (Table 3) for the glass-fiber filter samples ranged from 1.08×10^{-15} µCi/mL at Station 401 to 1.30×10^{-15} µCi/mL at Station 402. The mean annual gross beta activity (Table 4) for the glass-fiber filter samples ranged from 1.49×10^{-14} µCi/mL at Station 401 to 2.01×10^{-14} µCi/mL at Station 402.

Table 5 gives the CY2015 gross alpha and gross beta concentrations reported for CEMP stations surrounding the TTR. Because glass-fiber filters are also used in the air samplers at the CEMP stations, useful comparisons can be made to the glass-fiber filter samples from the TTR. Mean annual gross alpha concentrations at the TTR monitoring stations are higher than the values at all of the surrounding CEMP stations with the exception of Sarcobatus Flats and Alamo (Figure 24). The maximum gross alpha value for 2015 of 5.16×10^{-15} µCi/ml was recorded at Sarcobatus Flats. The mean annual gross beta concentrations at the CEMP stations (Figure 25) are higher than those measured at the TTR stations with the exception of TTR Station 402 being higher than Alamo and Sarcobatus Flats. All of the TTR maximum gross beta measurements are lower than the maximums measured at the surrounding CEMP stations with the exception of TTR Station 402 being higher than Beatty and Alamo.

Gamma spectroscopy identified only naturally occurring radionuclides in the particulate samples collected from TTR Stations 400, 401, and 402 during CY2015 (Table 6). The detected radionuclides occurred with varying frequency. Beryllium-7 and lead-210 were the most commonly detected. ^{241}Am, a product of ^{241}Pu decay, was not detected.

Table 5. Mean annual gross alpha and gross beta concentrations for 2015 reported at CEMP stations that surround the TTR.

Sampling Location	Gross alpha (x 10^{-15} µCi/mL)			Gross beta (x 10^{-14} µCi/mL)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Alamo	1.79	0.46	3.98	2.12	1.56	3.27
Beatty	1.05	0.49	1.76	1.94	1.34	3.23
Goldfield	1.05	0.59	1.77	1.85	1.18	3.06
Rachel	1.07	0.53	2.10	1.94	1.14	3.20
Sarcobatus Flats	1.81	0.58	5.16	2.05	1.22	3.09
Tonopah	1.02	0.42	1.82	1.78	1.16	3.14

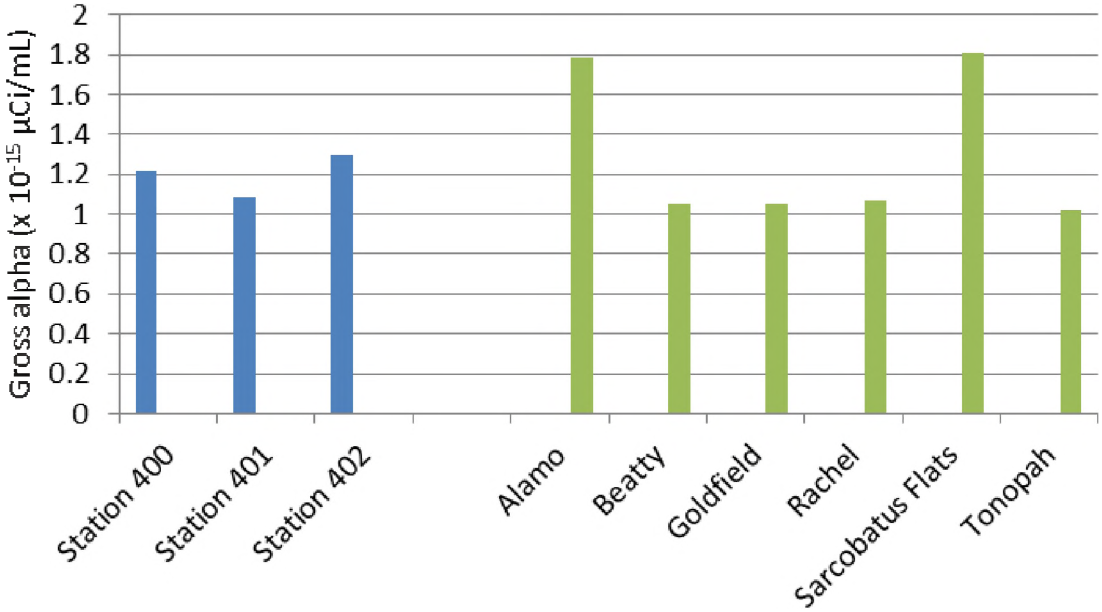

Figure 24. The mean annual gross alpha concentrations for the TTR samples (blue) compared with the mean annual gross alpha concentrations for samples collected at most of the surrounding CEMP stations (green).

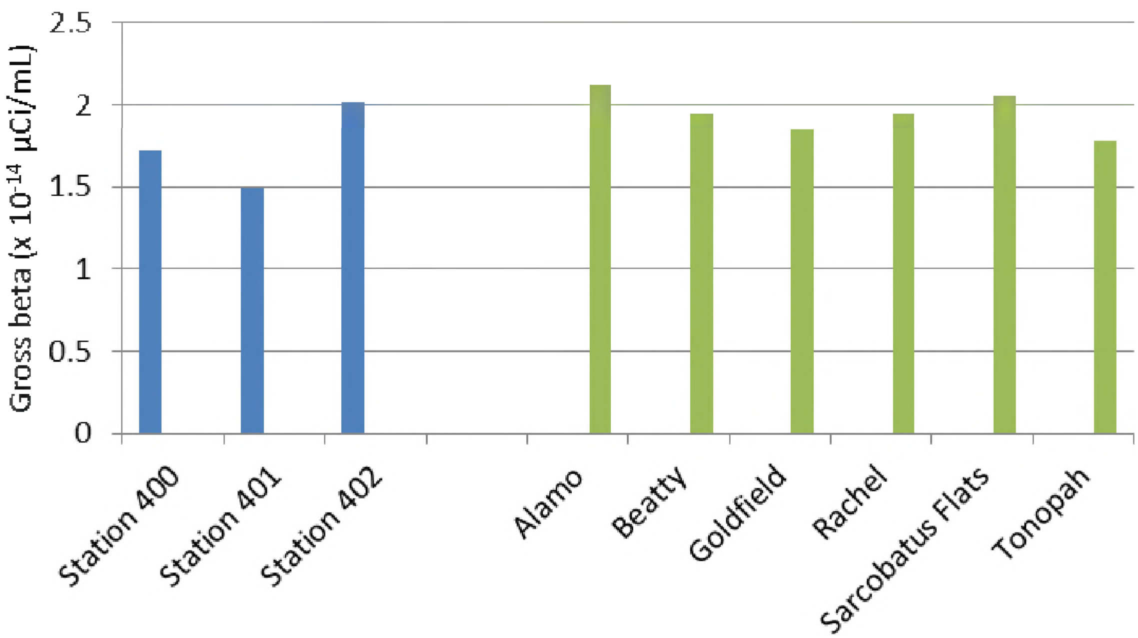

Figure 25. The mean annual gross beta concentrations for the TTR samples (blue) compared with the mean annual gross beta concentrations for samples collected at the surrounding CEMP stations (green).

Table 6. The number of CY2015 particulate samples in which naturally occurring radionuclides were identified by gamma spectroscopy varied by radionuclide and between stations.

Radionuclide	Number of Samples		
	Station 400	Station 401	Station 402
Beryllium-7 (Be-7)	25	24	23
Lead-210 (Pb-210)	17	13	13
Potassium-40 (K-40)	2	1	2
Lead-212 (Pb-212)	0	1	0
Bismuth-214 (Bi-214)	0	0	1
Protactinium-234m (Pa-234m)	0	0	1

GAMMA RADIATION OBSERVATIONS

Gamma radiation is measured using a PIC detector. A PIC detector is generally deployed to detect gamma radiation events that substantially exceed ambient radiation levels as a result of human activities. In the absence of such activities, ambient gamma radiation rates are recorded. These radiation values vary naturally among locations and reflect differences in altitude and latitude (cosmic radiation) and radioactivity in the soil (terrestrial radiation). Additionally, slight variations in gamma radiation at a single location may be caused by changes in weather (UNSCEAR, 2000).

The PIC data collected at the TTR air monitoring stations measure gamma radiation exposure every three seconds. These measurements are averaged every 10 minutes before being recorded in the station database. The 10-minute average gamma values for CY2015 recorded at TTR Stations 400, 401, and 402 are presented in Table 7 and Figure 26. Shown with the gamma record from each PIC are: the mean of all CY2015 10-minute gamma values at that station and the PIC mean plus and minus two standard deviations.

Table 7. Gamma exposure rate at the TTR measured by the PIC detectors.

Sampling Location	Average of 10-minute Gamma Exposure Rate (µR/hr)			
	Mean	Standard Deviation	Minimum	Maximum
Station 400	19.28	0.33	14.87	25.651
Station 401	20.03	1.04	16.44	28.88
Station 402	20.73	0.60	18.83	31.70

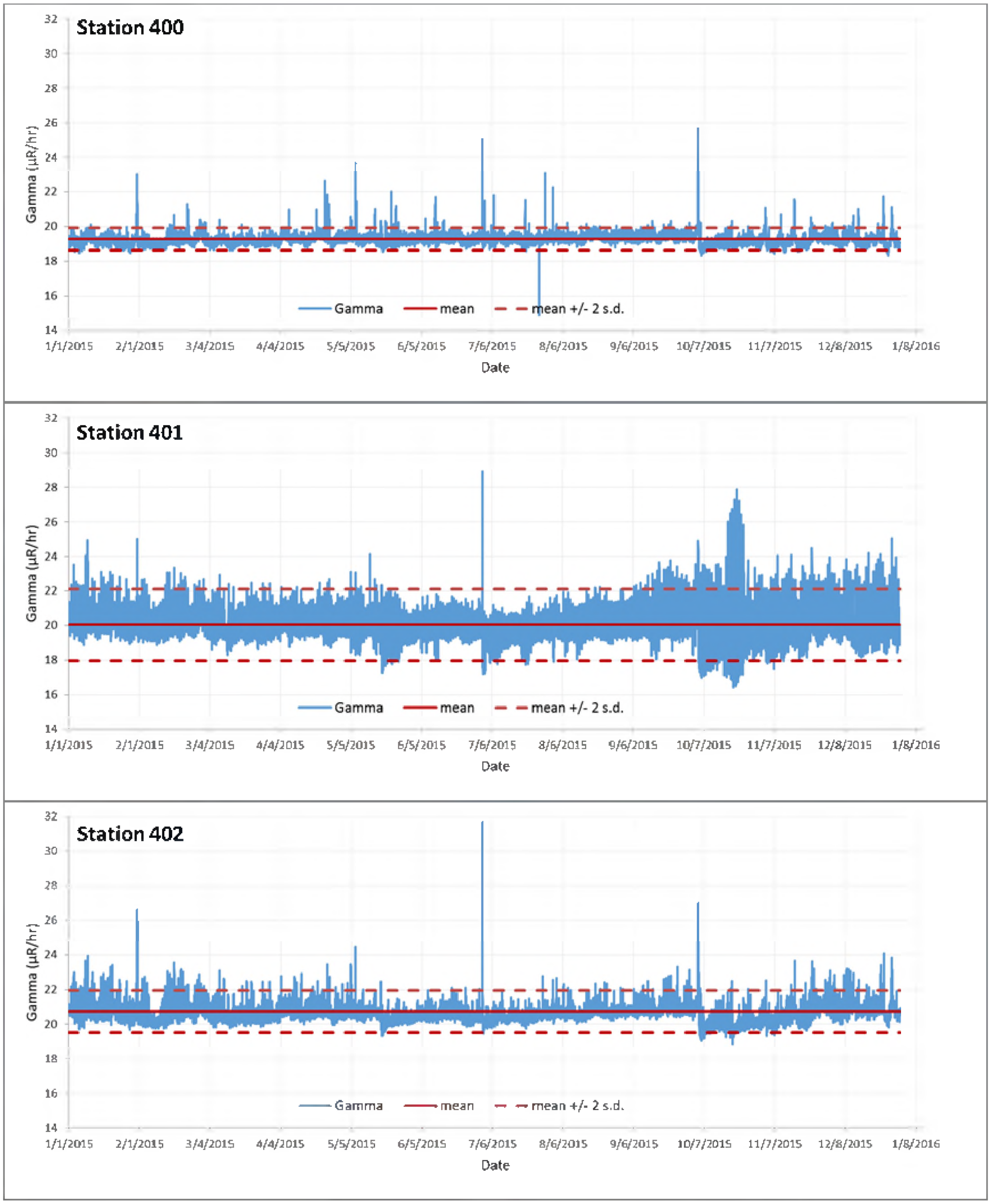

Figure 26. The CY2015 PIC gamma data for the TTR monitoring stations.

The average gamma exposure rates for the CEMP stations in the region are generally lower than the TTR stations with the exception of the CEMP station at Warm Springs Summit (Table 8). The 2013 annual report (Mizell *et al.*, 2015) examined atmospheric conditions coinciding with increases in gamma radiation. Observed meteorological conditions associated with intervals of increased gamma values commonly included increasing wind speeds, wind direction changes, increasing barometric pressure, increasing

Table 8. Gamma exposure rate measured with PICs at CEMP stations in the TTR region.

Sampling Location	Average of 10-minute Gamma Exposure Rate (µR/hr)			
	Mean	Standard Deviation	Minimum	Maximum
Alamo	13.23	0.44	10.45	21.19
Beatty	16.35	0.31	15.06	20.70
Goldfield	14.65	0.45	13.12	21.23
Rachel	14.85	0.52	13.55	21.41
Sarcobatus Flats	16.42	0.35	15.26	21.84
Tonopah	15.82	0.39	12.81	19.75
Warm Springs Summit	19.28	0.52	18.02	24.36

humidity, decreasing air temperature, and precipitation. These conditions also indicate a passing storm front, which suggests an association between storm front passage and intervals of increased gamma values. Additionally, high dust counts observed prior to the intervals of increased gamma values are likely the result of the winds associated with these storm fronts. The 2013 analysis concluded that the observed intervals of increased gamma values were not associated with wind transport of radionuclide-contaminated soil material.

A comparison of the CY2015 gamma measurements for Station 402 with precipitation measured at the monitoring station (Figure 27) reveals that many of the short-term gamma increases coincide with precipitation events. Comparisons of the TTR station measurements and the gamma record from the CEMP station at Warm Springs Summit also find coincidence between the timing of the gamma increases (Figure 28). These observations suggest that many of the higher gamma values are associated with precipitation or other widespread weather events, not migration of contaminated material from the Clean Slate sites.

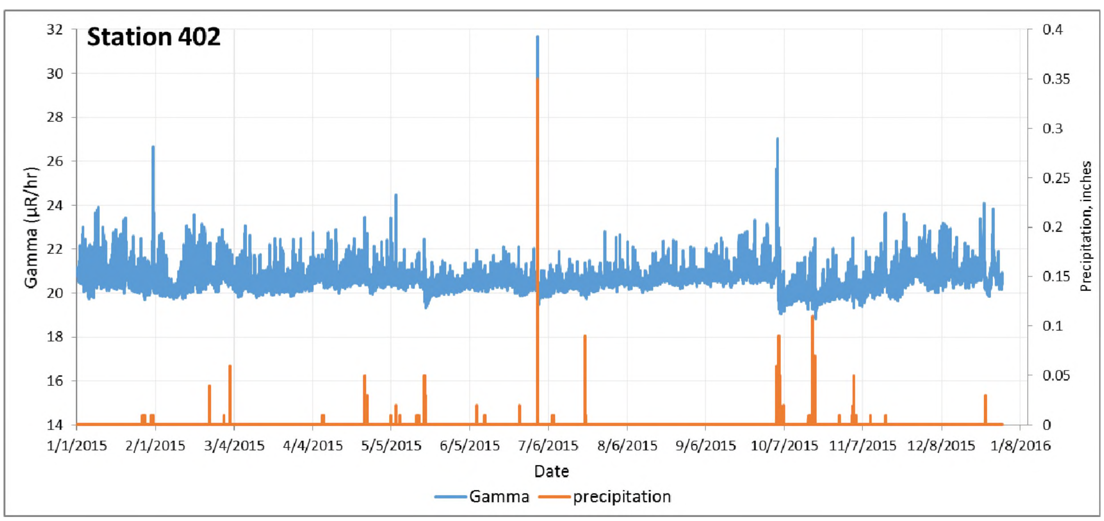

Figure 27. The CY2015 PIC gamma data and precipitation for TTR Station 402.

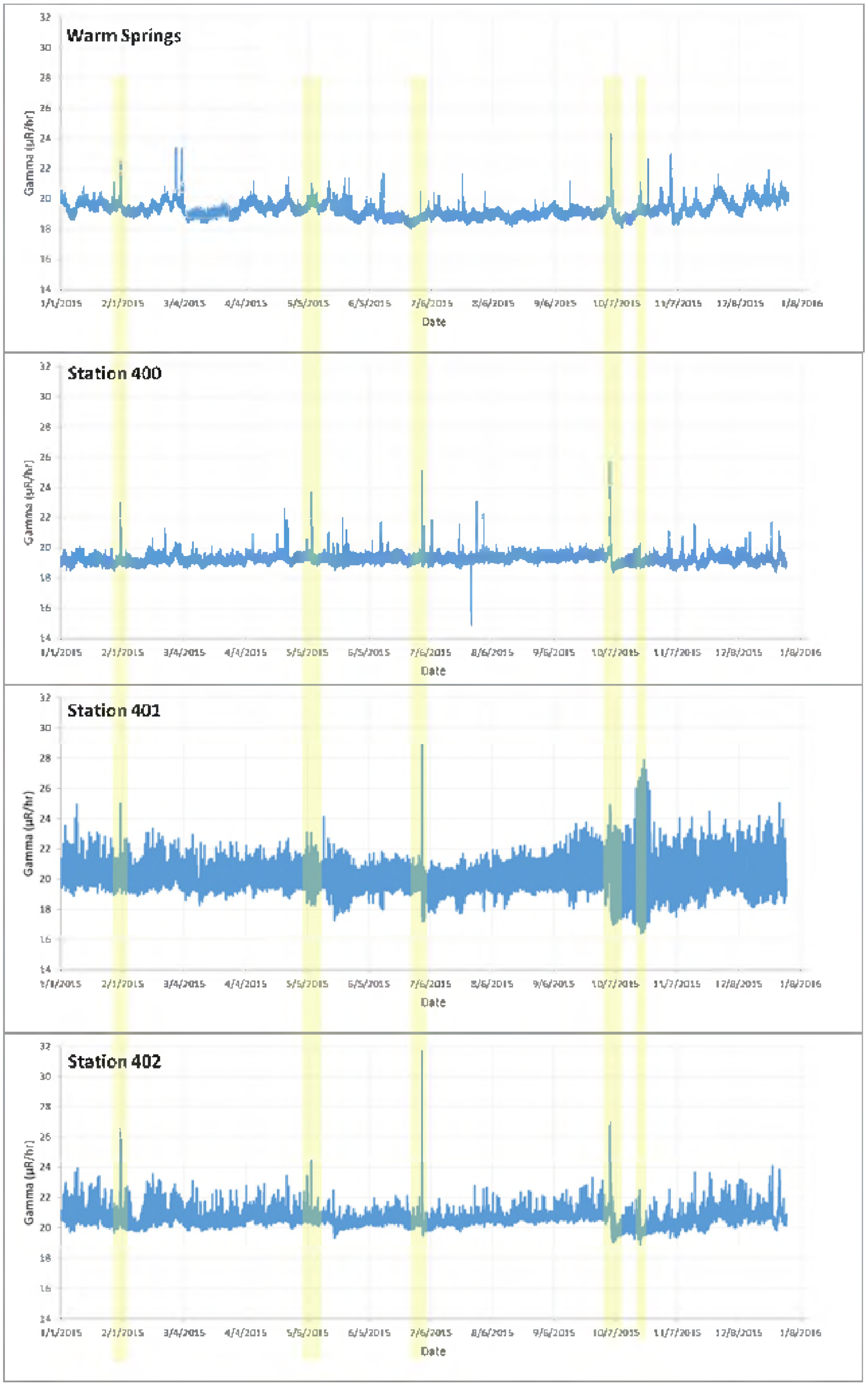

Figure 28. The CY2015 PIC gamma data for the CEMP station at Warm Springs Summit and the TTR stations that highlight select coincident times of increased values.

OBSERVATIONS OF SOIL TRANSPORT BY SALTATION

Saltation is the mechanism by which larger soil particles are transported across the ground surface. Generally, saltation involves particle sizes greater than approximately 50 µm. Particles are dislodged and carried a small distance in the air before falling to the ground (Figure 29). Transport paths usually follow a parabolic trajectory; the particles essentially bounce across the ground. The amount of time the particles are in the air and the distances traveled are functions of wind speed and particle mass. Saltation is important because the impact of saltated particles dislodges smaller particles and ejects them into the air where the smaller particles are transported by suspension.

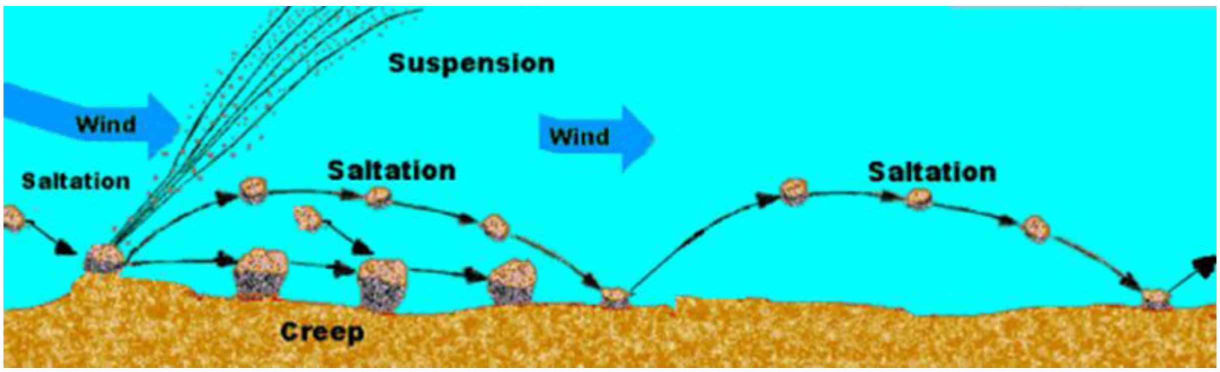

Figure 29. Diagram of the saltation process. Suspension of smaller particles ejected by the impact of a particle landing after saltation is depicted on the left.

Piezometric Sensor Results

The Sensit H11-LIN® (Sensit, Inc., Redlands, California) is deployed at TTR Stations 401 and 402 to measure the motion of soil particles saltating across the ground surface. The sensing area, which is set 10 cm (4 in) above the ground surface, wraps completely around the vertically oriented instrument and is capable of registering impacts from any direction. The sensing area is made of piezoelectric material that converts particle impacts to electrical impulses that are registered and summed over 10-minute intervals and subsequently stored on the station data logger. The saltation sensors are located in proximity to the meteorological towers at each station in areas that are free of recent disturbance and vegetation that might interfere with their operation. Windblown plant debris, such as tumbleweed, is cleared from the sensor area as needed. Raindrop impacts dislodge soil particles and eject particles, which may result in spurious impact counts on the saltation sensors during precipitation events. Therefore, saltation sensor data that are coincident with precipitation are not considered during data analyses.

Sand particle saltation is strongly dependent on wind speed. The relationship between wind speed and saltation particle counts was investigated by determining the average number of particle counts per 10-minute interval for wind speeds categorized in 8 km/hr (5 mph) wind speed classes (Table 9) after removing the intervals influenced by rain for the reasons described above. Figure 30 shows that the relationship between wind speed and saltation particle count is not linear. As wind speed increases past a threshold value (approximately

24 to 32 km/hr [15 to 20 mph]), the particle counts respond by increasing roughly exponentially. Below the 32 km/hr (20 mph) wind class, both Stations 401 and 402 show similarly low saltation counts. At wind speeds above 32 km/hr (20 mph), the saltation counts at Station 402 are somewhat greater than what is observed at Station 401, though the shapes of the curves are very similar and show an exponential-like increase in saltation counts with wind speed class. There could be a real difference in the amount of saltation-sized particles between the sites (Station 401 is adjacent to a lakebed with fine-grained playa deposits) or the difference in saltation counts could be a localized effect that depends on the placement of the Sensit® in respect to local changes in vegetation and crust strength. Vegetation in close proximity (30-50 cm) to the Sensit® sensors is cleared during installation, but it is possible that vegetation farther away could influence local conditions. Some sand transport occurs in the lower wind speed classes as can be seen in Figure 30B (log scale on y-axis) but the magnitude of this intermittent transport is very small. There is a strong, linear relationship between average saltation counts and average PM_{10} concentration (Figure 31).

Table 9. Average saltation particle impact counts by wind speed class at TTR air monitoring Stations 401 and 402.

Wind Speed Class (mph)	Duration (hours)	Average Wind Speed (mph)	Average Particle Counts (count/10-min)
Station 401			
0-5	4,127.50	2.79	0.003
5-10	2,570.33	7.11	0.028
10-15	1,112.67	12.18	0.173
15-20	538.33	17.09	1.441
20-25	129.67	21.86	5.877
25-30	31.33	27.15	5.172
30-35	7.67	31.95	38.156
35-40	1.17	36.30	133.857
Total hours	8,518.7		
Station 402			
0-5	4,372.67	2.78	0.026
5-10	2,178.50	7.08	0.458
10-15	1,077.33	12.26	1.323
15-20	516.33	17.10	6.922
20-25	129.50	21.67	11.772
25-30	32.50	27.51	9.251
30-35	9.33	31.73	58.175
35-40	0.83	36.14	183.600
Total hours	8,317.00		

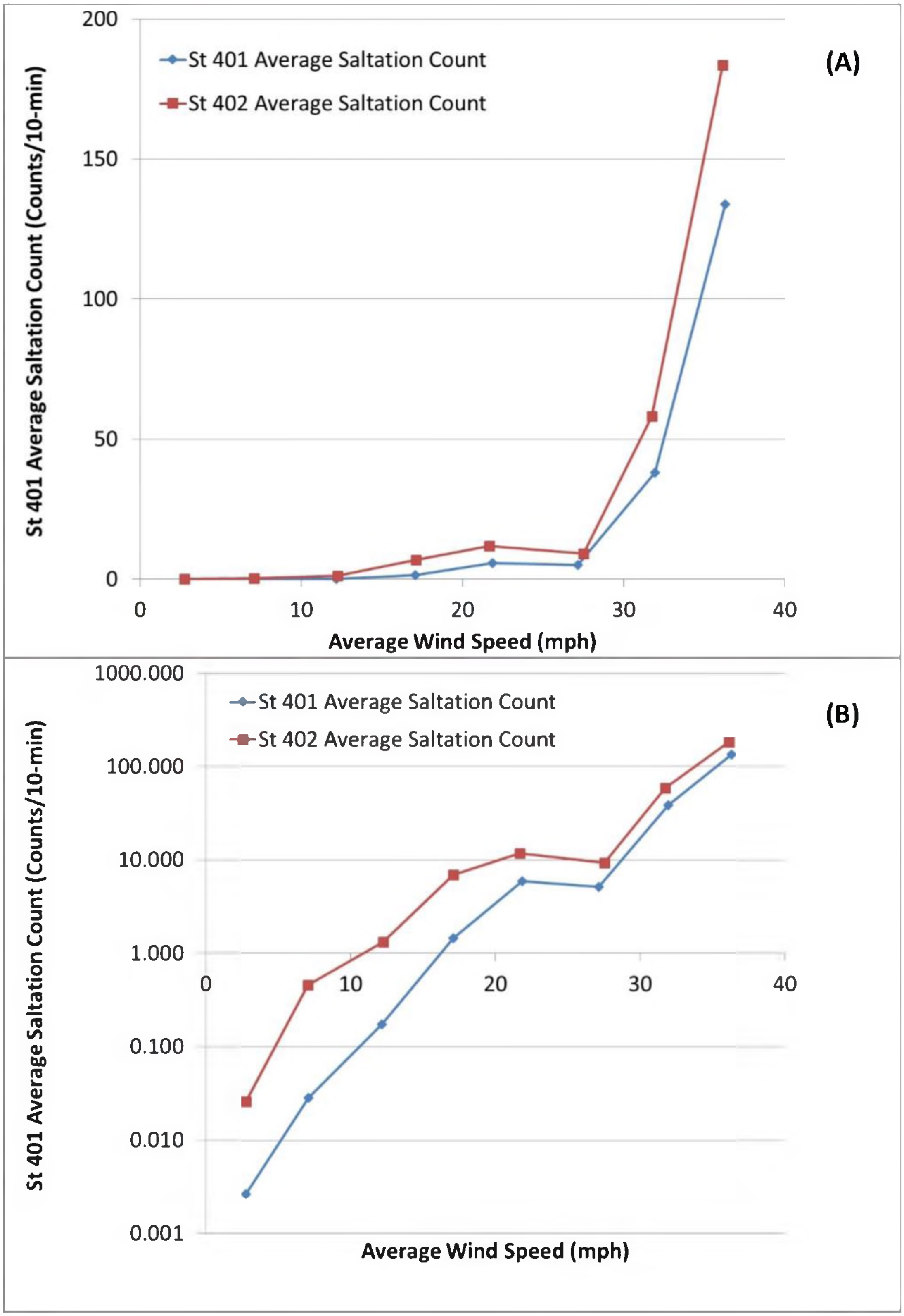

Figure 30. Linear (A) and log (B) scale relationships of particle counts and wind speed. Average saltation counts generally increase rapidly as the wind speed increases above 20 mph at both TTR Stations 401 and 402.

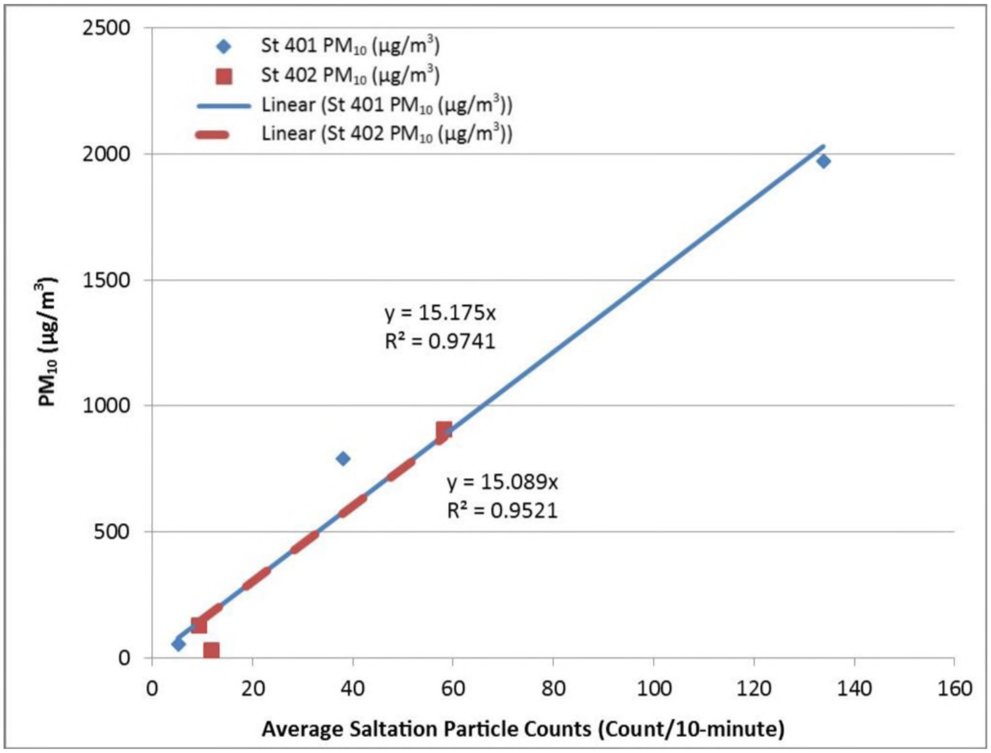

Figure 31. Regression of PM_{10} against saltation counts by wind speed class.

Saltation Trap Results

The Sensit® piezometric instruments provide real-time saltation activity that can be used to pinpoint exact transport events when analyzed in conjunction with wind speed data. One of the drawbacks of the Sensit® instrument is that it provides count information but not the mass flux. To estimate the transport flux, the BSNE traps were installed at TTR Stations 401 and 402 to provide integrated mass samples. The design and installation of the BSNE samplers is described in the station instrumentation section.

The BSNEs at the TTR Clean Slate I and III were originally installed on April 1, 2014. Each BSNE collector was sequentially numbered from 1 to 24. To minimize errors when collecting samples, it was agreed to always install odd numbered BSNEs toward the south-southeast and even number BSNEs toward the north-northwest (see Figure 32 and 33). Therefore, the material transported from Clean Slate sites by southerly winds would be collected in odd numbered BSNEs and material transported by northwesterly winds would be collected by the even numbered BSNEs. On April 1, 2014, BSNEs 1 to 6 and 7 to 12 were installed at the Clean Slate III and Clean Slate I site, respectively. Samples were not collected for over a year in order to allow accumulation of enough material for laboratory analysis. On June 24, 2015, samples from BSNEs 1 to 12 were collected for the first time from the field sites and clean BSNEs numbered 13 to 24 were installed at Clean Slate III and I; BSNEs 13-18 and 19-24 were installed at the Clean Slate III and Clean Slate I sites, respectively. When samples were collected for the second time on February 16, 2016, the first full BSNE rotation occurred and BSNEs 13 to 24 were collected and BSNEs 1 to 12 were installed in the field in the same order and location as on April 1, 2014.

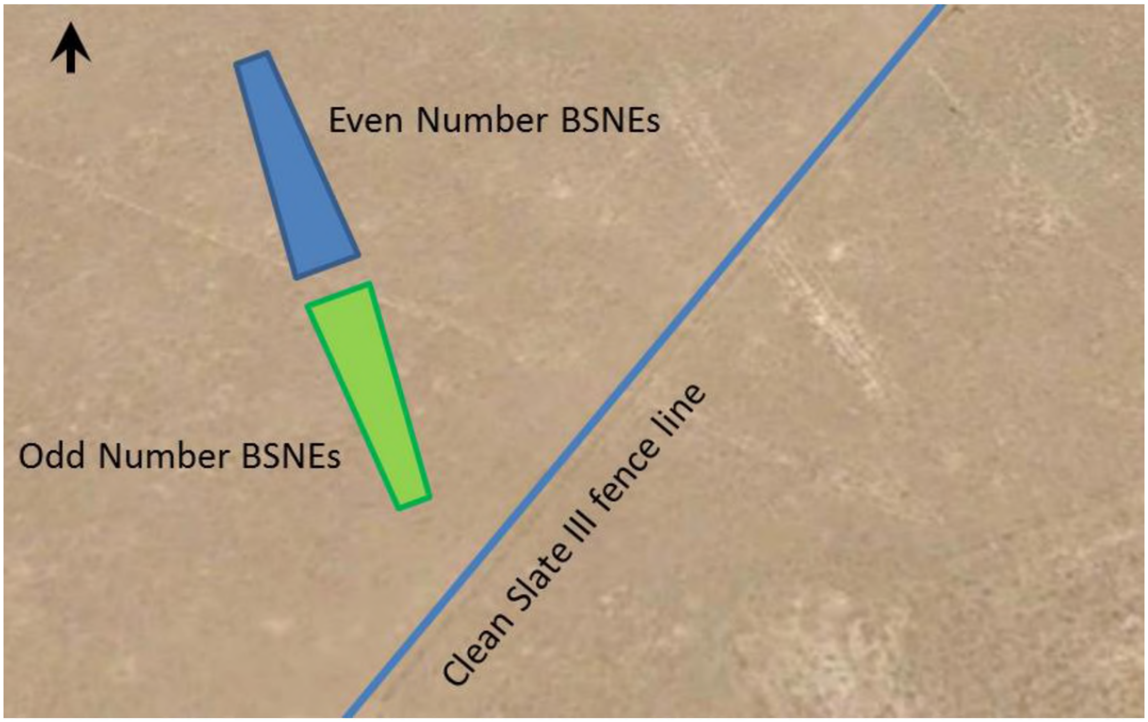

Figure 32. TTR Clean Slate III Station 401 BSNE alignment.

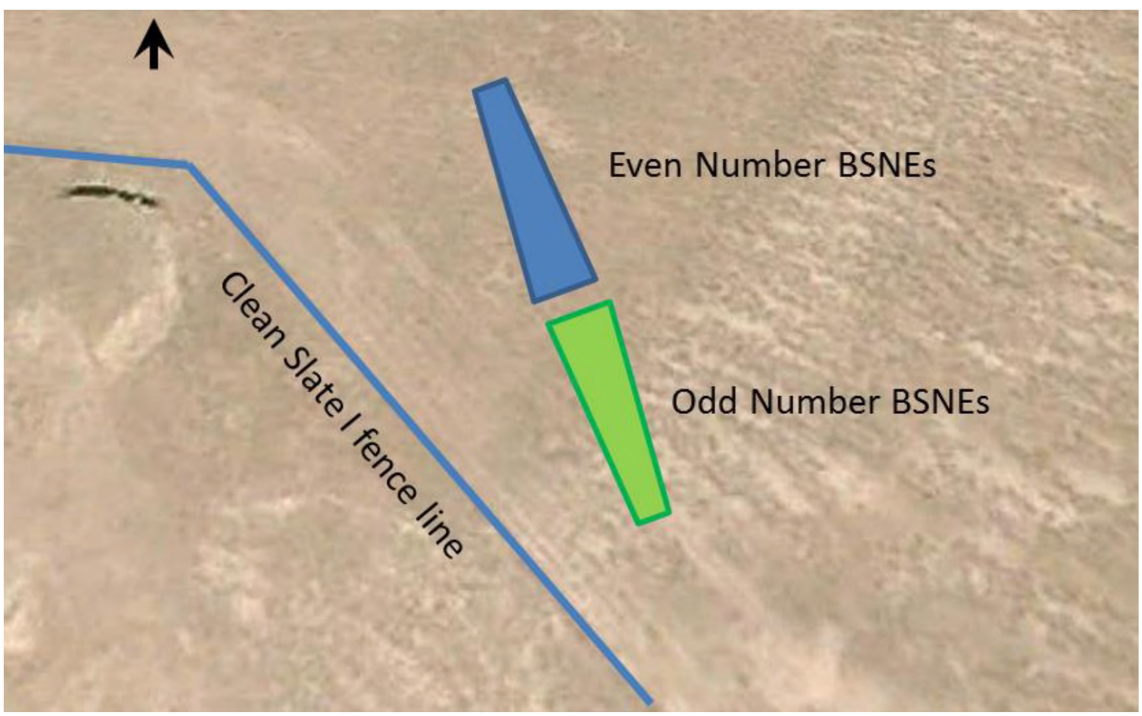

Figure 33. TTR Clean Slate I Station 402 BSNE alignment.

When the BSNEs were collected on June 24, 2015, and February 17, 2016, the traps were processed and cleaned in the field and the samples were initially weighed and packaged for the radiological and soil size distribution lab analysis. To determine collected weight, each BSNE was wiped on the outside to remove any rain splatter debris, the top section was removed (see Figure 34), and the collected sample in the bottom was inspected. The bottom of each BSNE containing the samples was weighed on a lab balance with a 0.1 g resolution and the weight was recorded in the field datasheet. After being cleaned and dried, the bottom of the BSNEs were weighed and the net collected soil weight was determined by subtracting the two measured weights. It is important to note that this net weight also included an unknown amount of water and other impurities that could not easily be removed on-site. Deionized water was used to carefully wash out the collected soil samples into 0.5 L plastic bottles (see Figure 35). Even after a year of collection time, samples from the three odd numbered BSNEs at each Clean Slate site were combined into one 0.5 L plastic bottle for lab analysis because of the relatively small amount of collected material. The same procedure was followed for the even numbered BSNEs at each location, which resulted in the collection of two composite samples for lab analyses for each Clean Slate site.

Figure 34. TTR BSNE sample collection February 17, 2016.

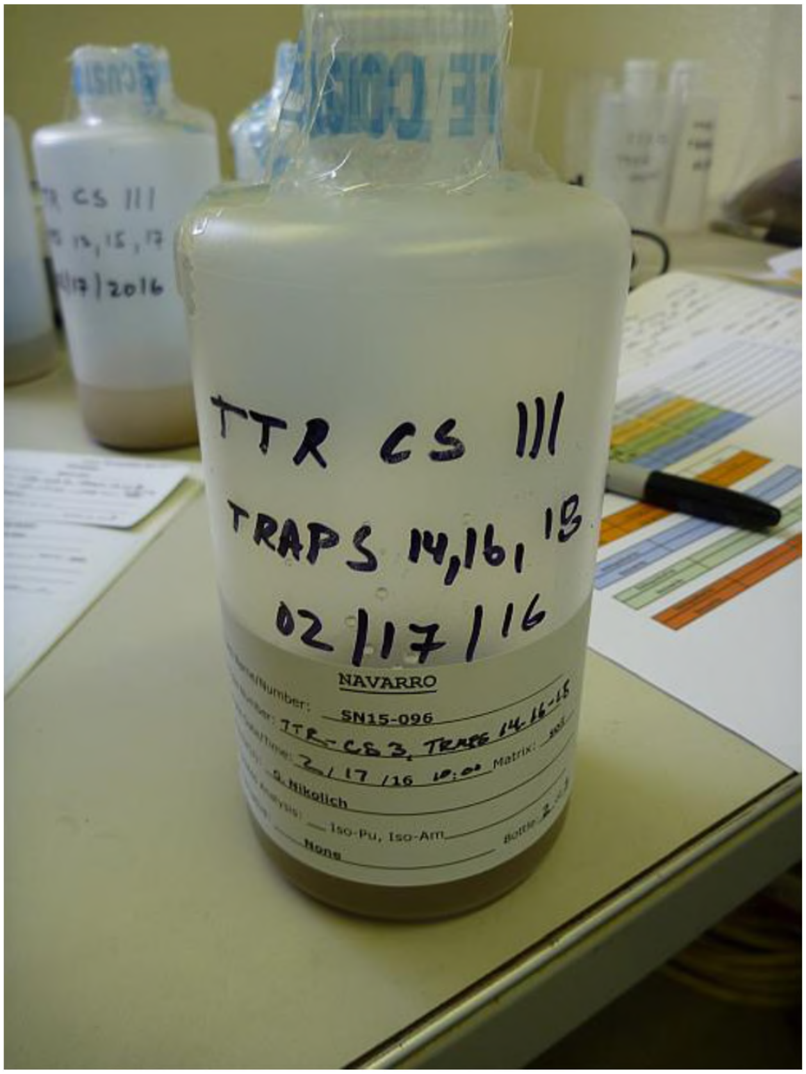

Figure 35. TTR BSNE samples collection February 17, 2016.

The first collection interval—between April 1, 2014, and June 24, 2015— was 449 days and the second collection interval—between June 24, 2015, and February 16, 2016— was 237 days. Table 10 shows the field weights with notes on when collected soil samples were saturated with rain water (also see Figures 36 and 37). The BSNEs 16 and 17 had enough rain water to suspend the collected soil particles and the soil weight could not be reliably determined in the field. Soil size distribution and radiological analyses were performed in a laboratory. The samples collected in June 2014 were separated into two broad size ranges by a mean particle diameter of 63 to 250 µm (micrometers) and less than 63 µm in diameter (the laboratory did not report on the >250 µm particle size fraction). The soil analysis for samples collected in February 2016 was separated into three size ranges: greater than 250 µm, between 65 and 250 µm, and less than 63 µm in diameter. The results of the gravimetric lab analysis are shown in Table 11.

Table 10. Field weights of collected soil samples and collection dates/times.

Clean Slate Site	BSNE Number	Start Date	End Date	Net Weight (g)
Clean Slate III	T1	April 1, 2014	June 24, 2015	2.6
Clean Slate III	T3	April 1, 2014	June 24, 2015	2.7
Clean Slate III	T5	April 1, 2014	June 24, 2015	2.4
Clean Slate III	T2	April 1, 2014	June 24, 2015	3.9
Clean Slate III	T4	April 1, 2014	June 24, 2015	4.3
Clean Slate III	T6	April 1, 2014	June 24, 2015	4.4
Clean Slate I	T7	April 1, 2014	June 24, 2015	1.9
Clean Slate I	T9	April 1, 2014	June 24, 2015	2.3
Clean Slate I	T11	April 1, 2014	June 24, 2015	2.2
Clean Slate I	T8	April 1, 2014	June 24, 2015	4.7
Clean Slate I	T10	April 1, 2014	June 24, 2015	5.5
Clean Slate I	T12	April 1, 2014	June 24, 2015	5.8
Clean Slate III	T13	6/24/15 11:30	2/17/16 9:45	3.2
Clean Slate III	T15	6/24/15 11:30	2/17/16 9:45	3.9
Clean Slate III	T17	6/24/15 11:30	2/17/16 9:45	20.3*
Clean Slate III	T14	6/24/15 11:30	2/17/16 9:45	2.5
Clean Slate III	T16	6/24/15 11:30	2/17/16 9:45	7.1*
Clean Slate III	T18	6/24/15 11:30	2/17/16 9:45	2.5
Clean Slate I	T19	6/24/15 11:30	2/17/16 10:30	7.1
Clean Slate I	T21	6/24/15 11:30	2/17/16 10:30	7.0
Clean Slate I	T23	6/24/15 11:30	2/17/16 10:30	9.5
Clean Slate I	T20	6/24/15 11:30	2/17/16 10:30	2.7
Clean Slate I	T22	6/24/15 11:30	2/17/16 10:30	2.4
Clean Slate I	T24	6/24/15 11:30	2/17/16 10:30	2.2

*Indicated water saturated/wet samples with invalid field mass data

Table 11. Gravimetric lab analysis.

BSNE #	Mass > 250 µm (g)	Mass 63 µm to 250 µm (g)	Mass < 63 µm (g)	Total Mass Lab (g)
TTR CS III Traps: 1, 3, 5	No data	6.1901	1.2831	7.4732
TTR CS III Traps: 2, 4, 6	No data	10.7498	2.7761	13.5259
TTR CS I Traps: 7, 9, 11	No data	4.1662	1.5089	5.6751
TTR CS I Traps: 8, 10, 12	No data	11.2255	3.1872	14.4127
TTR CS III Traps: 13, 15, 17	3.1662	4.9124	1.4545	9.5331
TTR CS III Traps: 14, 16, 18	1.0522	4.011	1.3109	6.3741
TTR CS I Traps: 19, 21, 23	7.9649	8.5704	1.8583	18.3936
TTR CS I Traps: 20, 22, 24	1.0297	4.4114	1.849	7.2901

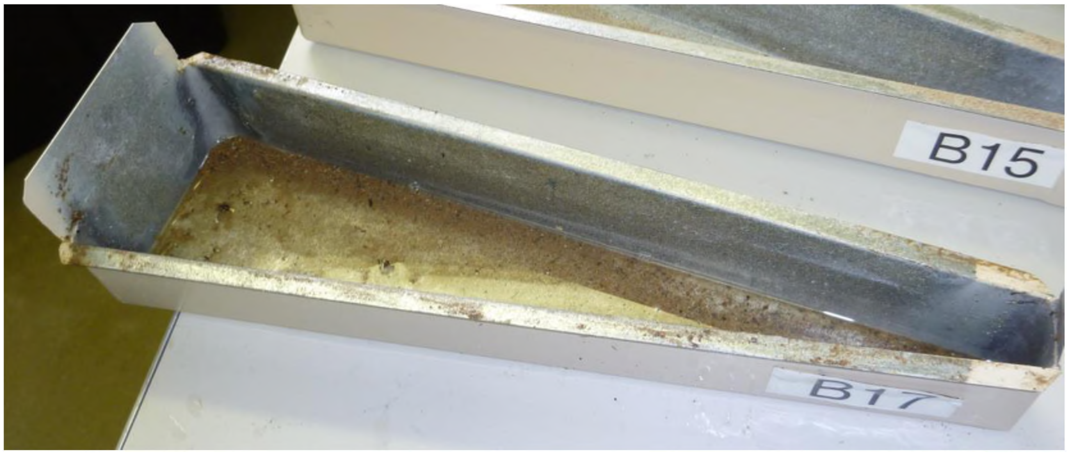

Figure 36. Rain water collected in BSNE 17 during February 17, 2016, sample collection.

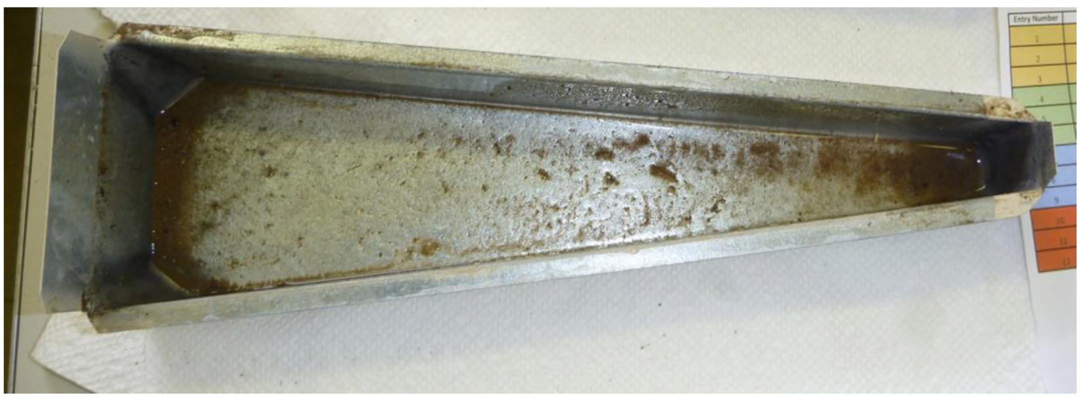

Figure 37. Rain water collected in BSNE 16 during February 17, 2016, sample collection.

The results of the lab soil size analysis for BSNE samples collected at the Clean Slate III and I sites between April 1, 2014, and June 24, 2015, are shown in Figures 38 and 39. Both Clean Slate sites show a very similar trend for two sets of the installed BSNEs. The total masses from the odd numbered traps collecting saltating particles downwind from Clean Slate III and I were 7.47 g and 5.67 g, respectively. The even numbered traps collecting material from the upwind direction (moving toward the Clean Slate sites) had a total of 13.52 g and 14.41 g for Clean Slate III and I, respectively. These results show that during the period between April 1, 2014, and June 24, 2015, net soil and dust transport was from the northwest and toward the Clean Slate sites. Data from Stations 401 and 402 indicate that the area encounters stronger winds from the northwest. The soil transport magnitude is very similar at both sites despite the difference in saltation magnitude registered by the Sensit® saltation sensors. The individual BSNE data show a consistent trend. The samples from BSNEs show that particles between 63 and 250 μm represent 74 percent to 82 percent of the collected mass (see Figure 39).

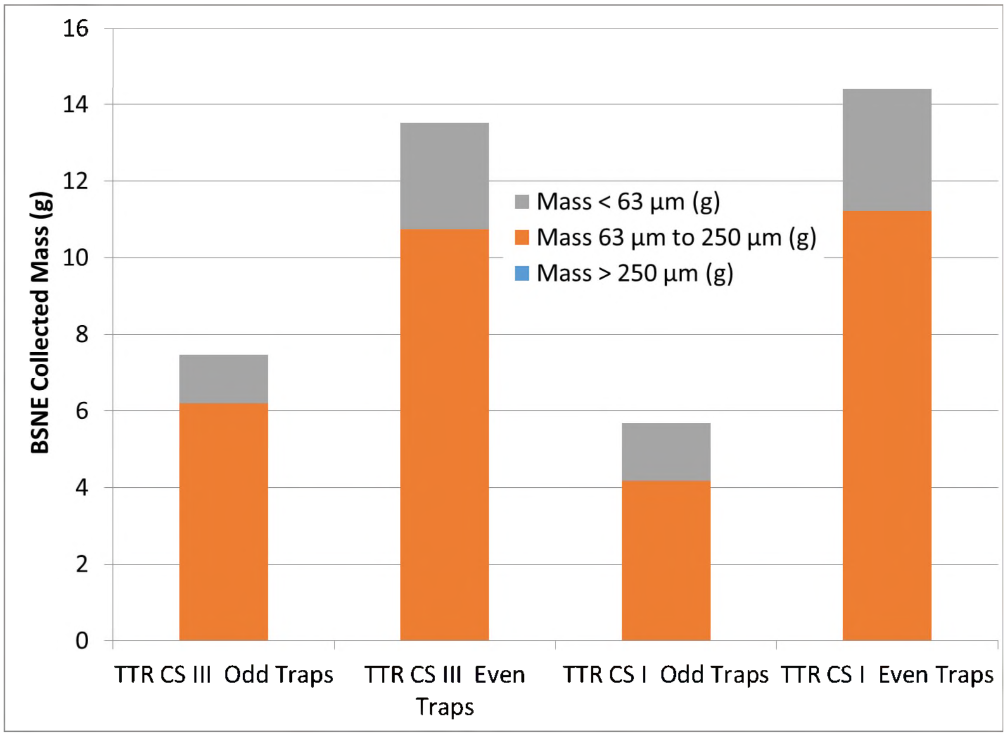

Figure 38. BSNE April 1, 2014, to June 24, 2015, collection period soil sample size distribution. The laboratory did not report the >250 µm size fraction mass.

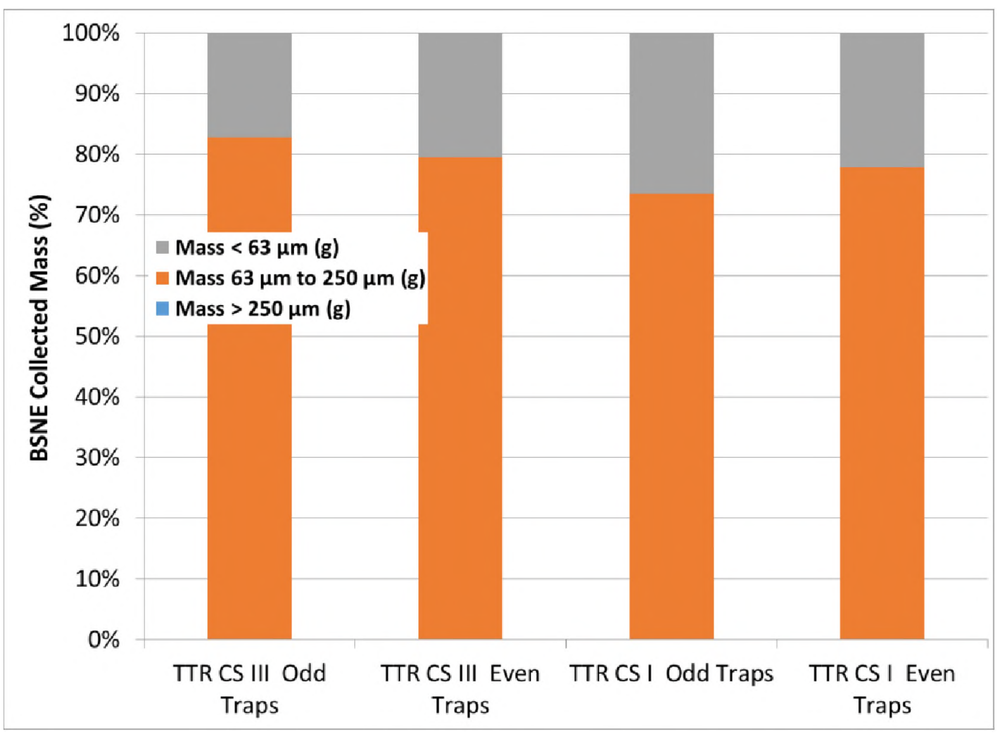

Figure 39. BSNE April 1, 2014, to June 24, 2015, collection period normalized soil sample size distribution. The laboratory did not report the >250 µm size fraction mass.

The results of lab analysis for soil size distribution of the second set of samples collected from BSNEs installed at Clean Slate III and I are shown in Figures 40 and 41. The BSNE second collection period was between June 24, 2015, and February 17, 2016. This lab analysis reported on soil samples in three size fractions. The samples contain a sizeable mass fraction for particles greater than 250 µm and this is especially true for samples collected from odd numbered traps that collect material downwind from Clean Slate sites. This size fraction represents approximately 43 percent of the total of collected mass at Clean Slate I for traps that collect material that came from the contaminated areas. In the case of Clean Slate III, this size fraction is approximately 34 percent of the total mass that came across Clean Slate III. This size fraction is only approximately 15 percent for even numbered BNSEs installed at both Clean Slate I and III that collect material driven by northwesterly winds.

The total mass transport for odd numbered BSNEs was 9.53 and 18.39 g for Clean Slate III and I, respectively. The total transport for the even numbered traps was 6.37 and 7.29 g for Clean Slate III and I, respectively. This suggests that the net soil transport between June 24, 2015, and February 17, 2016, was coming from the Clean Slate sites and large particles 250 µm or greater account for most of the net positive mass flux from the Clean Slate sites. At Clean Slate III, the total mass of particles less than 250 µm was 8.08 g from odd numbered traps and 5.32 g for even numbered traps. The total mass for particles less than 63 µm in diameter was 1.45 and 1.31 g for two sets of traps at Clean Slate III. A similar trend is true for Clean Slate I. Taking into consideration that the BSNE data from the earlier collection period suggest the opposite trend, it appears that the transport rates and directions at the Clean Slates I and Clean slates III sites are somewhat variable over time. A longer measurement record is needed before a more certain estimate of long-term average of the transport regime can be determined.

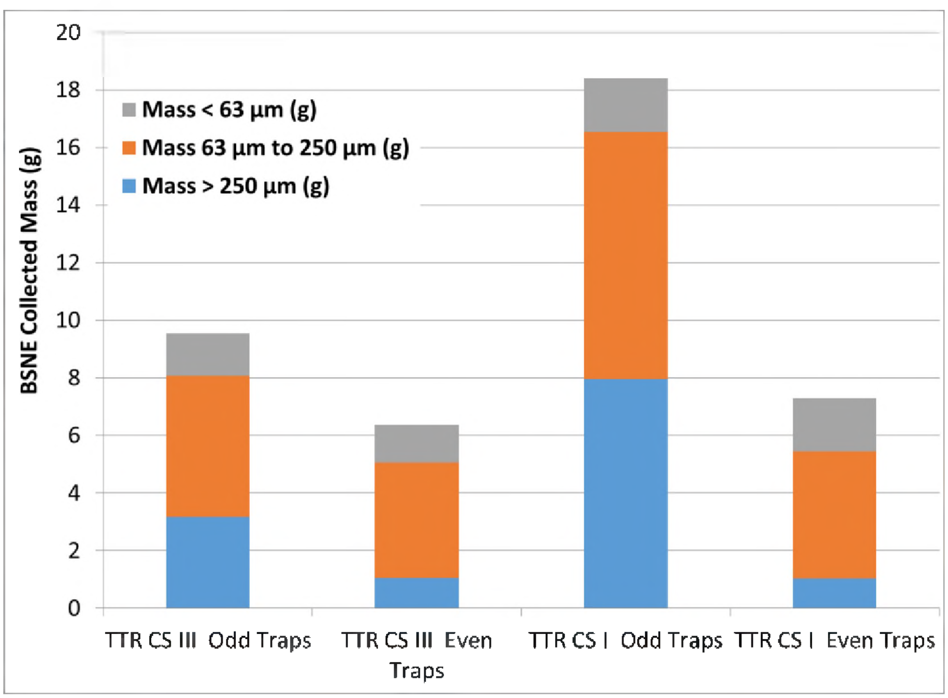

Figure 40. BSNE June 24, 2015, to February 17, 2016, collection period soil sample size distribution.

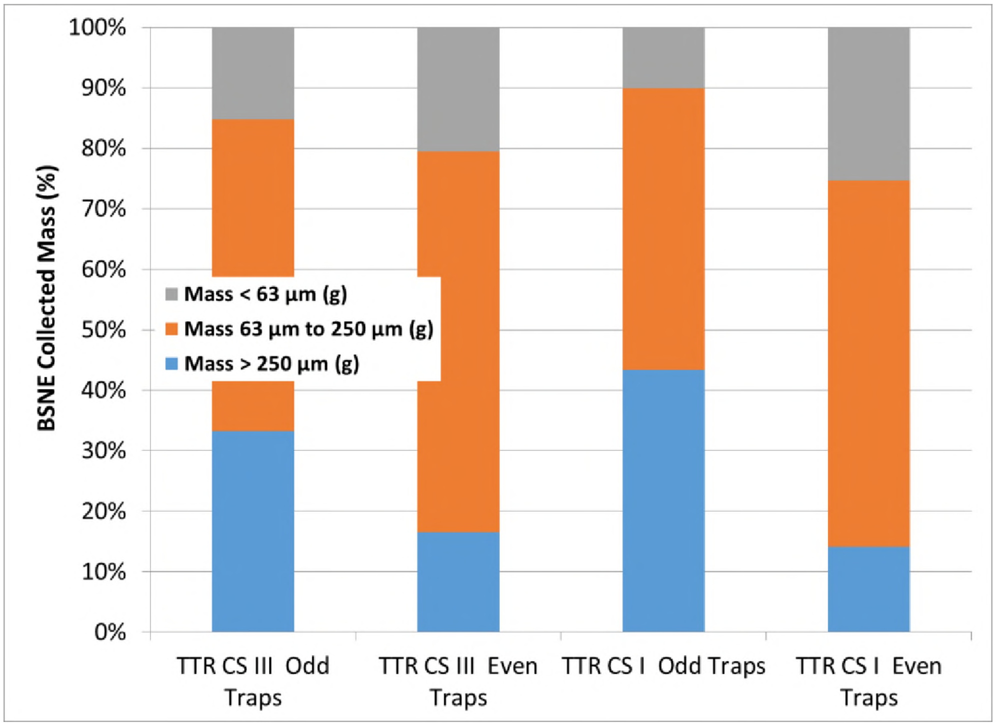

Figure 41. BSNE June 24, 2015, to February 18, 2016, collection period normalized soil sample size distribution.

Radiological analyses were performed for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am (Table 12) for all BSNE samples. Because of the small sample size, each set of three traps pointing in the same direction was composited for analysis. In general, higher concentrations are associated with the smaller particle size fraction, although there is a consistent exception to this for all of the radionuclides from Clean Slate I upwind in 2015 (Traps 8, 10, 12) and downwind in 2016 (Traps 19, 21, 23) (Figures 42, 43, 44). There are no consistent differences between the concentrations from the upwind traps (even numbers) compared with the downwind traps (odd numbers). The $^{239+240}$Pu concentrations for all of the composited samples are on the order of 500 to 15,000 times higher than background (assumed to be 0.014 pCi/g per Turner *et al.* [2003]), but 20 to 600 times lower than the 25 millirem per year action level (equivalent to a $^{239+240}$Pu concentration of 4,750 pCi/g). The $^{239+240}$Pu/^{238}Pu ratio is also between three and eight times higher than that from atmospheric weapons testing fallout in the northern hemisphere (fallout ratio of 30 per Turner *et al.* [2003]), which indicates an additional source for $^{239+240}$Pu and is consistent with the location adjacent to the Clean Slate safety tests.

Table 12. Alpha spectroscopy analytical results for samples collected in saltation traps.

Isotope Concentrations at Clean Slate Sites		
BSNE #	**Size Fraction**	
	< 63 µm	**63 to 250 µm**
Pu-239/240 (pCi/g)		
TTR CS I Traps: 7, 9, 11	61.7	7.88
TTR CS I Traps: 8, 10, 12	27.6	74.9
TTR CS I Traps: 19, 21, 23	30.1	165
TTR CS I Traps: 20, 22, 24	79.5	8.49
TTR CS III Traps: 1, 3, 5	90.2	11.4
TTR CS III Traps: 2, 4, 6	74.4	36.5
TTR CS III Traps: 13, 15, 17	141	26.8
TTR CS III Traps: 14, 16, 18	210	20.8
Am-241 (pCi/g)		
TTR CS I Traps: 7, 9, 11	3.83	0.5865
TTR CS I Traps: 8, 10, 12	1.77	3.41
TTR CS I Traps: 19, 21, 23	1.33	6.55
TTR CS I Traps: 20, 22, 24	3.23	0.547
TTR CS III Traps: 1, 3, 5	5.38	0.791
TTR CS III Traps: 2, 4, 6	3.57	2.06
TTR CS III Traps: 13, 15, 17	5.8	1.2
TTR CS III Traps: 14, 16, 18	8.68	0.977
Pu-238 (pCi/g)		
TTR CS I Traps: 7, 9, 11	0.457	0.09765
TTR CS I Traps: 8, 10, 12	0.301	0.523
TTR CS I Traps: 19, 21, 23	0.122	1.0055
TTR CS I Traps: 20, 22, 24	0.515	0.0632
TTR CS III Traps: 1, 3, 5	0.646	0.125
TTR CS III Traps: 2, 4, 6	0.532	0.296
TTR CS III Traps: 13, 15, 17	0.858	0.285
TTR CS III Traps: 14, 16, 18	1.46	0.168

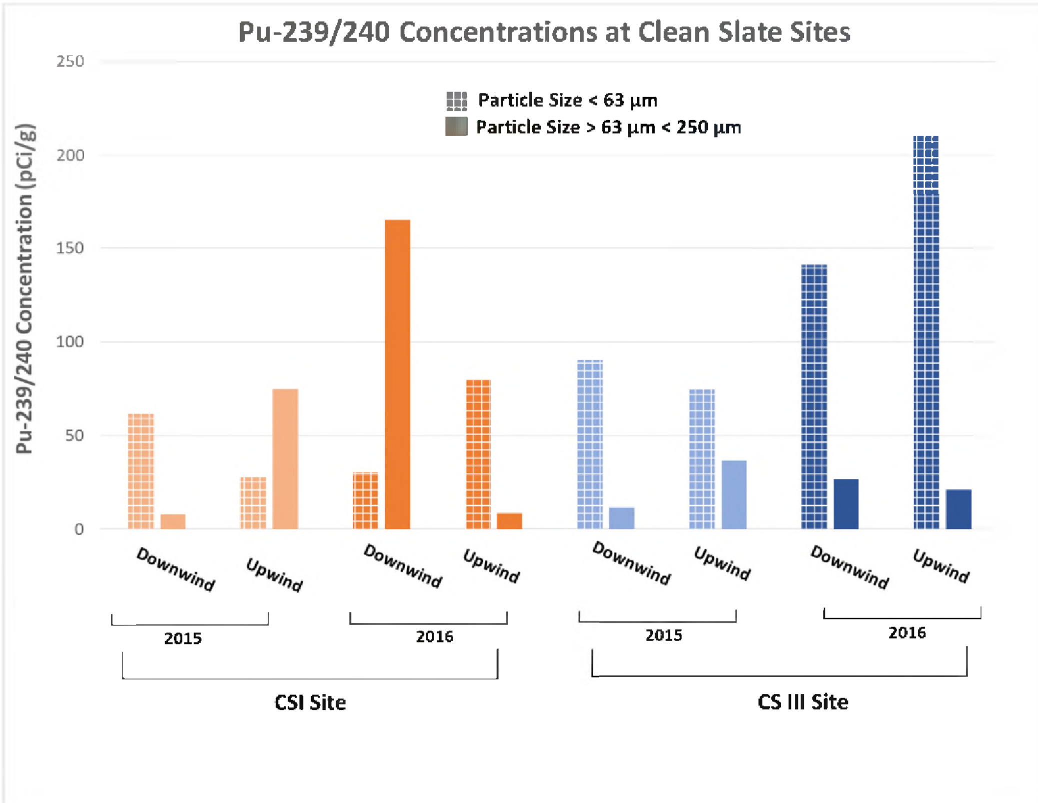

Figure 42. $^{239+240}Pu$ concentrations in samples from the saltation traps.

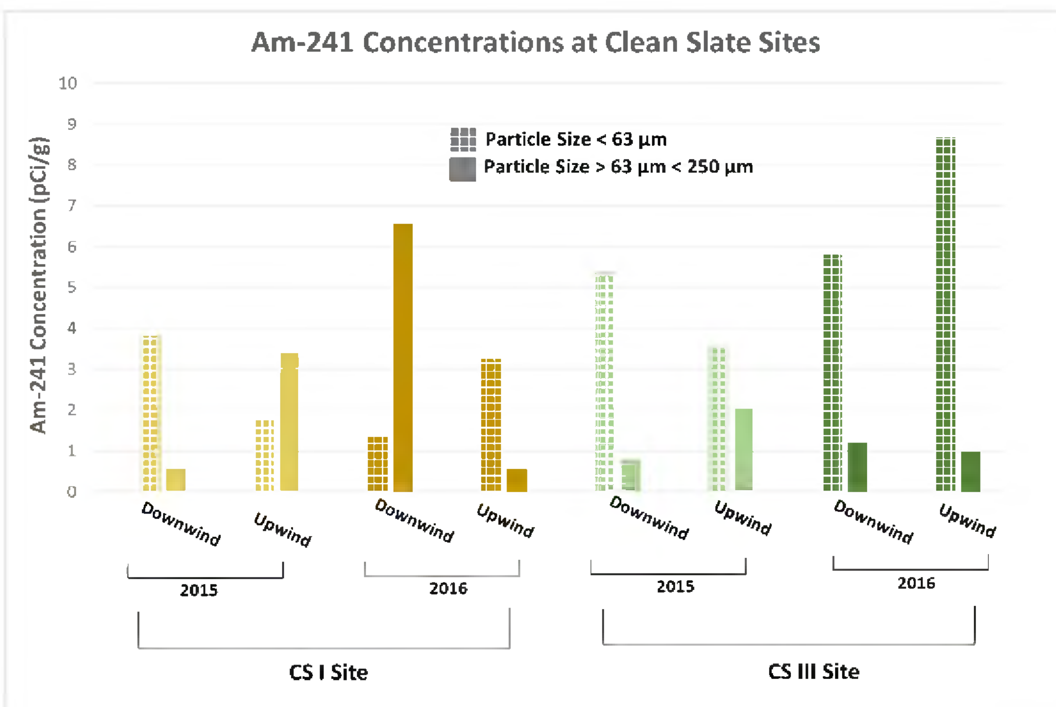

Figure 43. ^{241}Am concentrations in samples from the saltation traps.

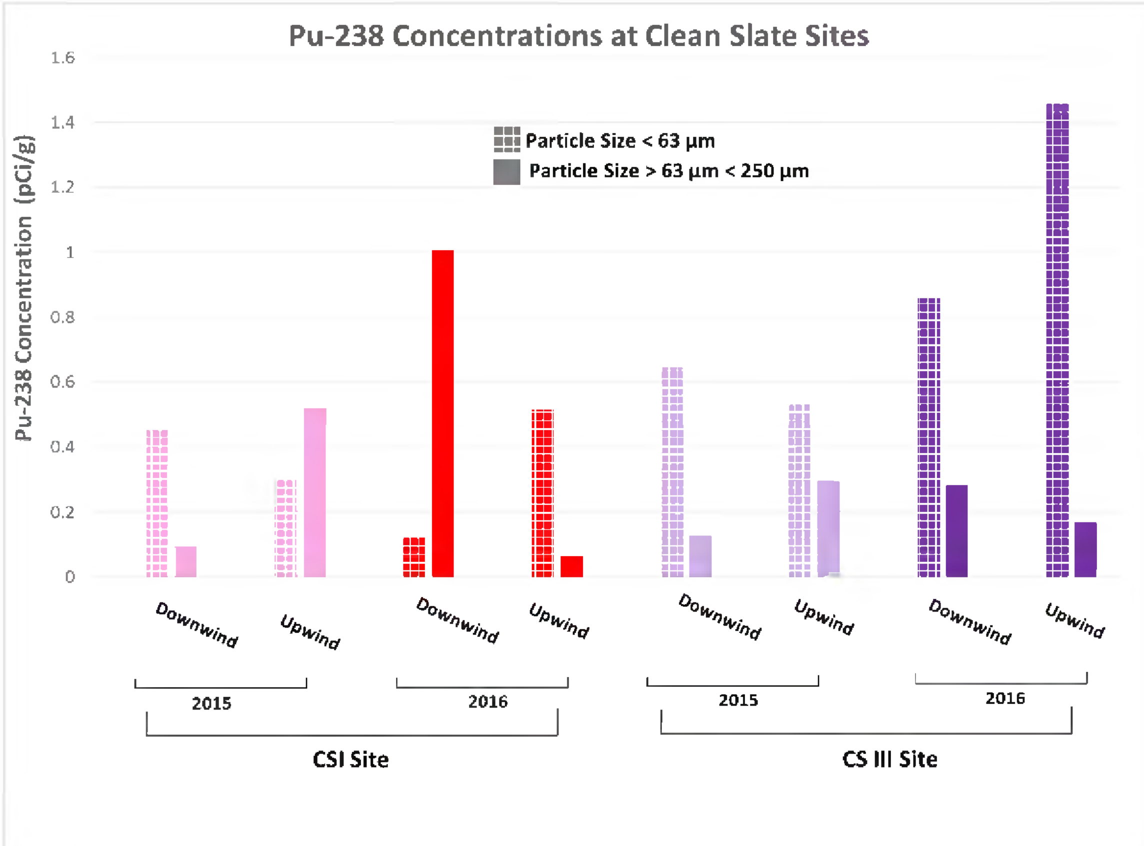

Figure 44. ^{238}Pu concentrations in samples from the saltation traps.

OBSERVATIONS OF SOIL TRANSPORT BY SUSPENSION

Table 13 summarizes wind speed and the corresponding PM_{10} concentration by wind speed class for Stations 400, 401, and 402. More than 90 percent of the time, the wind speed at all three stations is below 24 km/hr (15 mph) and the corresponding average PM_{10} concentrations are below 11-12 µg/m^3. Although PM_{10} concentrations generally increase as wind speed increases, the PM_{10} concentrations remain fairly low until winds exceed approximately 32 km/hr (20 mph). At Station 400, PM_{10} concentrations increase with increasing wind speed and exceed 1,498 µg/m^3 for the strongest winds between 57 and 64 km/hr (35 and 40 mph). At Stations 401 and 402, PM_{10} concentrations also increased consistently with increasing wind speed and reached a maximum of 1,972 and 2,478 µg/m^3 when winds were above 57 and 64 km/hr (35 and 40 mph), respectively. During CY2015, there was a somewhat higher frequency of winds over 35 mph compared with CY2013 and CY2014, which resulted in higher PM_{10} concentration for those time periods.

Table 13. Summary of wind and PM_{10} data for Stations 400, 401, and 402 for CY2015.

Wind Speed Class (mph)	Duration (hours)	Frequency (%)	Cumulative Frequency (%)	Average Wind Speed (mph)	PM_{10} ($\mu g/m^3$)
Station 400					
0-5	3,406.00	40.300%	40.300%	3.23	6.91
5-10	3,121.00	36.928%	77.227%	7.12	6.43
10-15	1,239.50	14.666%	91.893%	12.16	7.19
15-20	509.33	6.026%	97.920%	17.08	8.59
20-25	143.50	1.698%	99.617%	21.84	18.85
25-30	27.83	0.329%	99.947%	26.55	182.54
30-35	4.17	0.049%	99.996%	31.31	1,148.77
35-40	0.33	0.004%	100.000%	36.42	1,498.11
Total hours	8,451.67				
Station 401					
0-5	4,127.50	48.452%	48.452%	2.79	12.62
5-10	2,570.33	30.173%	78.625%	7.11	7.45
10-15	1,112.67	13.062%	91.687%	12.18	5.75
15-20	538.33	6.319%	98.006%	17.09	7.00
20-25	129.67	1.522%	99.528%	21.86	15.06
25-30	31.33	0.368%	99.896%	27.15	53.62
30-35	7.67	0.090%	99.986%	31.95	789.94
35-40	1.17	0.014%	100.000%	36.30	1,972.13
Total hours	8,518.7				
Station 402					
0-5	4,372.67	52.575%	52.575%	2.78	12.95
5-10	2,178.50	26.193%	78.768%	7.08	11.72
10-15	1,077.33	12.953%	91.722%	12.26	10.38
15-20	516.33	6.208%	97.930%	17.10	15.66
20-25	129.50	1.557%	99.487%	21.67	32.52
25-30	32.50	0.391%	99.878%	27.51	131.05
30-35	9.33	0.112%	99.990%	31.73	908.53
35-40	0.83	0.010%	100.000%	36.14	2,478.43
Total hours	8,317.00				

Various wind speeds occur with similar frequencies at all stations (Figure 45). The small percentage of winds above 20 mph is responsible for dust events. Light winds (0 to 8 km/hr [0 to 5 mph]) are most common. Wind speeds in excess of 24 km/hr (15 mph) occur less than 10 percent of the time and wind speeds in excess of 32 km/hr (20 mph) occur less than 3 percent of the time.

At Stations 400, 401, and 402, the average PM_{10} concentration increases in an approximately exponential pattern with linear increases in wind speed (Figure 46). All three monitoring stations show similar trends and dependence on wind speed when it comes to PM_{10} concentration. Figure 47 shows a similar trend between monitoring stations when it comes to $PM_{2.5}$ concentration and corresponding wind speed class.

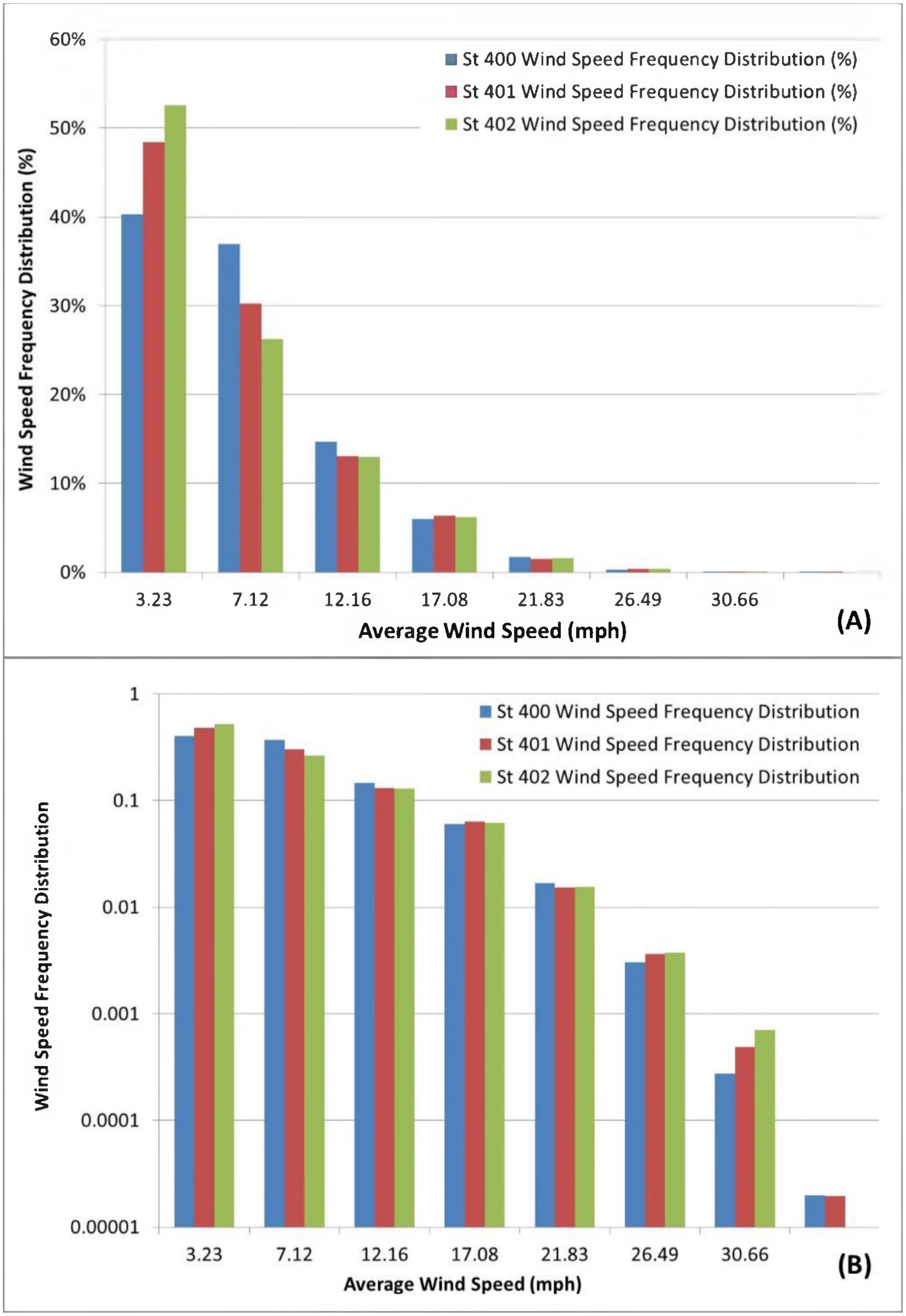

Figure 45. Wind speed frequency (A is linear scale and B is log scale) by wind class for Stations 400, 401, and 402 for CY2015. The portion of time wind speed falls within a given class is plotted against the average wind speed for that class.

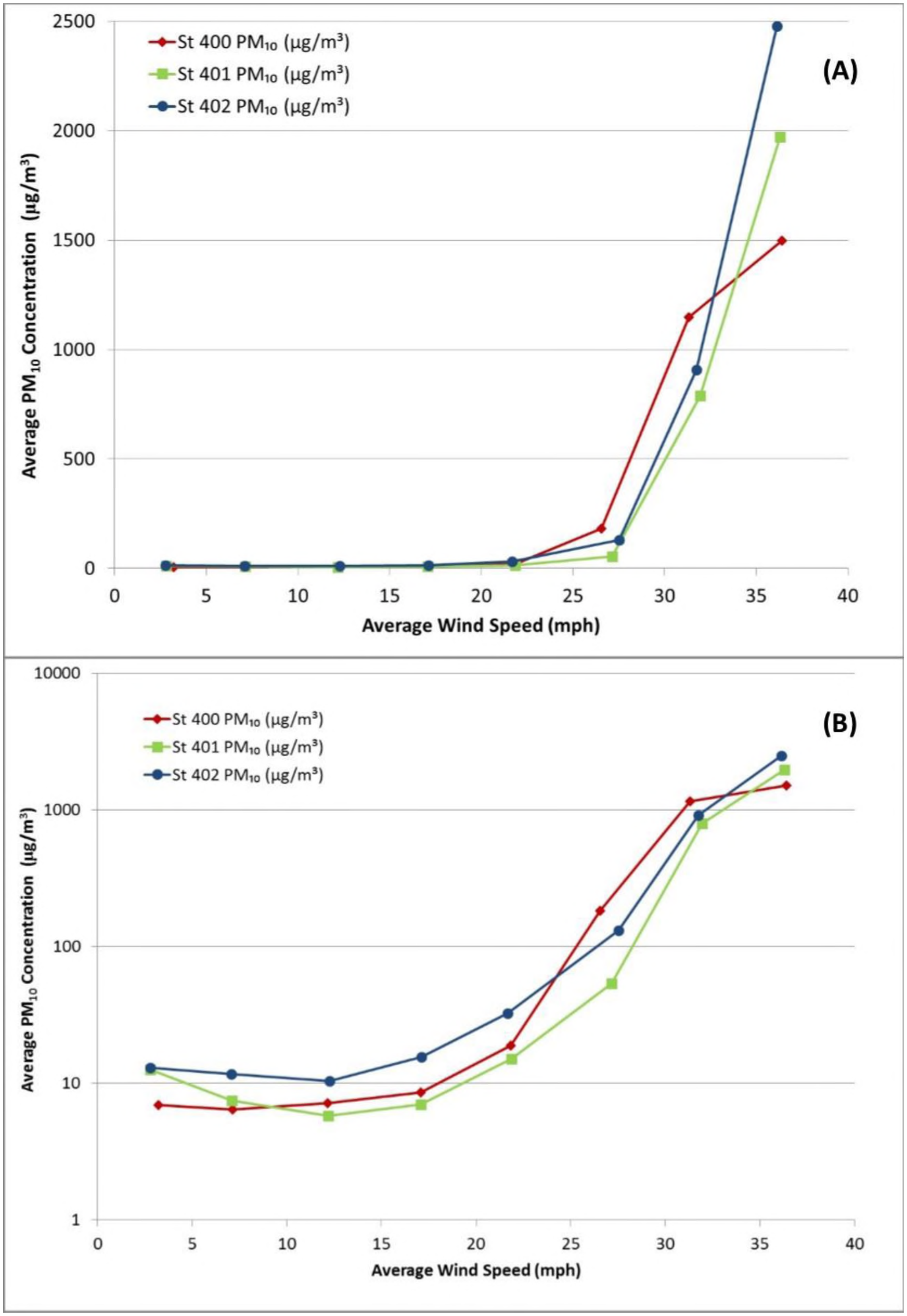

Figure 46. PM_{10} trends as a function of wind speed for Stations 400, 401, and 402 for CY2015; PM_{10} concentration is on a linear scale in (A) and log scale in (B).

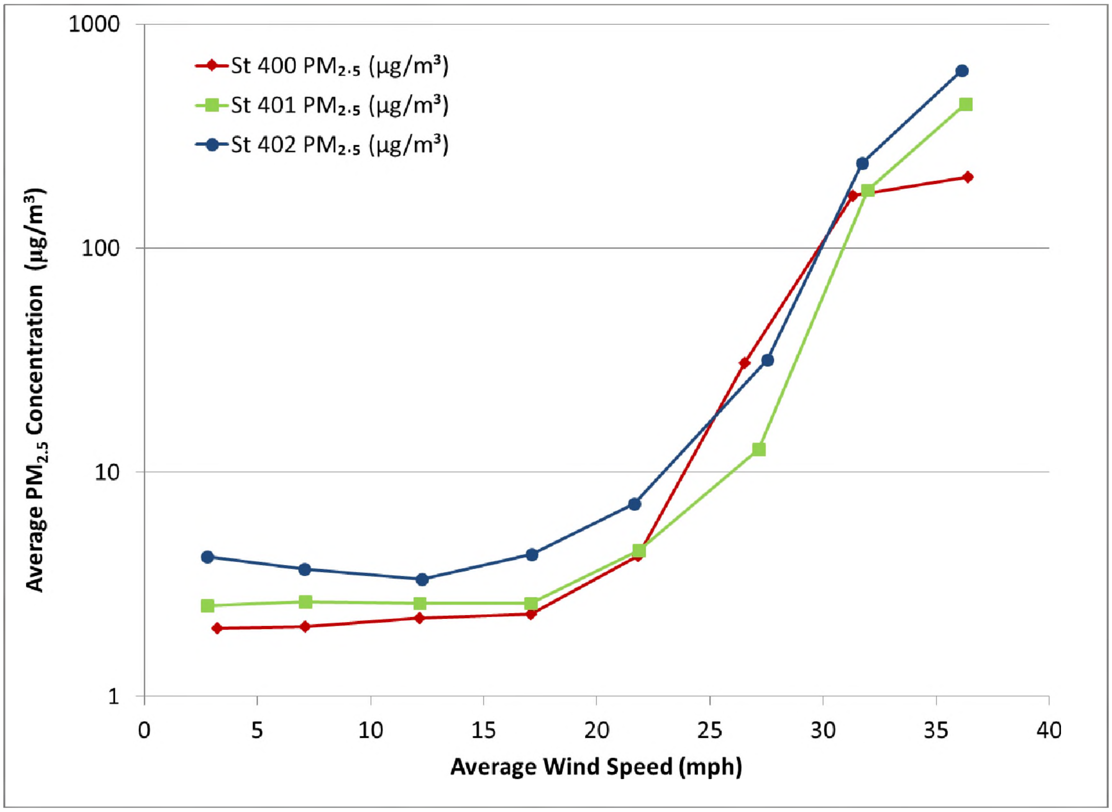

Figure 47. $PM_{2.5}$ trends as a function of wind speed for Stations 400, 401, and 402 for CY2015; $PM_{2.5}$ concentration plotted on a logarithmic scale to illustrate wide dynamic range of $PM_{2.5}$ concentrations.

OBSERVATIONS OF SOIL TRANSPORT BY SUSPENSION FROM SOUTH AND NORTHWEST

The PM_{10} transport has been evaluated previously (Mizell *et al.*, 2014; Nikolich *et al.*, 2015) by establishing relationships between different wind speed classes and the corresponding average PM_{10} concentration. The data indicate an exponential-type increase in PM_{10} concentration with a linear increase in wind speeds over 24 km/hr (15 mph). Table 14 shows the frequency of winds from the south and northwest compared with all winds by 5 mph wind classes. All three stations show that for winds above 15 mph (those that generally cause saltation and dust transport), winds from the south and northwest occur with a frequency above 92 percent. The data in Table 15 show the average wind speed by wind class from south and northwest and the corresponding average PM_{10} concentration. Winds over 40 km/hr (25 mph) generally occur more frequently out of the northwest than the south and the associated PM_{10} is comparable or slightly higher for southerly winds (Figures 48, 49, and 50). This suggests that northeasterly winds may be associated with a greater degree of aeolian transport overall than southerly winds. One recommendation based on these data is to consider installation of monitoring stations at the southwesterly end of the contaminated area at Clean Slate I and III to obtain data to support of reject this hypothesis.

Table 14. Summary of wind speed, duration, and direction data for Stations 400, 401, and 402 for CY2015.

	Wind Speed Class (mph)	Total Duration (hours)	Duration from South (hours)	Duration from Northwest (hours)	Portion of Time from S and NW (%)
Station 400	0-5	3,406.00	953.17	1,520.33	72.6%
	5-10	3,121.00	1,538.17	1,177.83	87.0%
	10-15	1,239.50	733.50	419.67	93.0%
	15-20	509.33	356.00	136.33	96.7%
	20-25	143.50	103.17	37.50	98.0%
	25-30	27.83	11.33	16.17	98.8%
	25-30	27.83	11.33	16.17	98.8%
	30-35	4.17	1.17	3.00	100.0%
	Total hours	8,645.8	3,707.84	3,696.50	
Station 401	0-5	4,127.50	1,591.00	934.17	61.2%
	5-10	2,570.33	982.83	881.17	72.5%
	10-15	1,112.67	599.00	383.83	88.3%
	15-20	538.33	313.33	182.17	92.0%
	20-25	129.67	75.00	46.83	94.0%
	25-30	31.33	8.50	22.67	99.5%
	30-35	7.67	1.33	6.33	100.0%
	>35	1.17	0.00	1.17	100.0%
	Total hours	8,518.67	3,571.00	2,458.33	
Station 402	0-5	4,372.67	1,066.00	1,040.83	48.18%
	5-10	2,178.50	859.33	783.33	75.40%
	10-15	1,077.33	613.83	389.67	93.15%
	15-20	516.33	310.50	187.17	96.38%
	20-25	129.50	80.50	46.50	98.07%
	25-30	32.50	8.33	24.17	100.00%
	30-35	9.33	1.33	8.00	100.00%
	30-35	0.83	0.00	0.83	100.00%
	Total hours	8,317.00	2,939.83	2,480.50	

Table 15. Summary of wind and PM_{10} data for Stations 400, 401, and 402 for CY2015.

	Wind Speed Class (mph)	South Average Wind Speed (mph)	Northwest Average Wind Speed (mph)	Average PM_{10} for South wind ($\mu g/m^3$)	Average PM_{10} for Northwest Wind ($\mu g/m^3$)
Station 400	0-5	3.38	3.34	6.22	7.74
	5-10	7.20	7.07	6.62	6.19
	10-15	12.21	12.12	6.11	8.26
	15-20	17.17	16.89	6.69	12.89
	20-25	21.79	21.99	13.11	35.19
	25-30	26.17	26.79	26.91	294.79
	30-35	30.79	31.51	39.92	1,579.99
Station 401	0-5	2.81	2.87	12.29	11.47
	5-10	7.28	7.27	7.02	8.03
	10-15	12.21	12.17	5.89	5.81
	15-20	17.07	17.14	7.11	7.04
	20-25	21.91	21.83	17.08	11.61
	25-30	26.78	27.30	97.53	36.65
	30-35	31.12	32.13	414.29	869.02
	35-40	none	36.30	none	1,972.13
Station 402	0-5	2.64	2.86	11.03	12.16
	5-10	7.38	7.21	12.22	8.20
	10-15	12.32	12.22	11.87	8.11
	15-20	17.13	17.09	16.25	14.22
	20-25	21.65	21.73	37.19	24.10
	25-30	27.47	27.53	103.02	140.72
	30-35	30.65	31.91	159.22	1033.41
	35-40	none	36.14	none	2,478.43

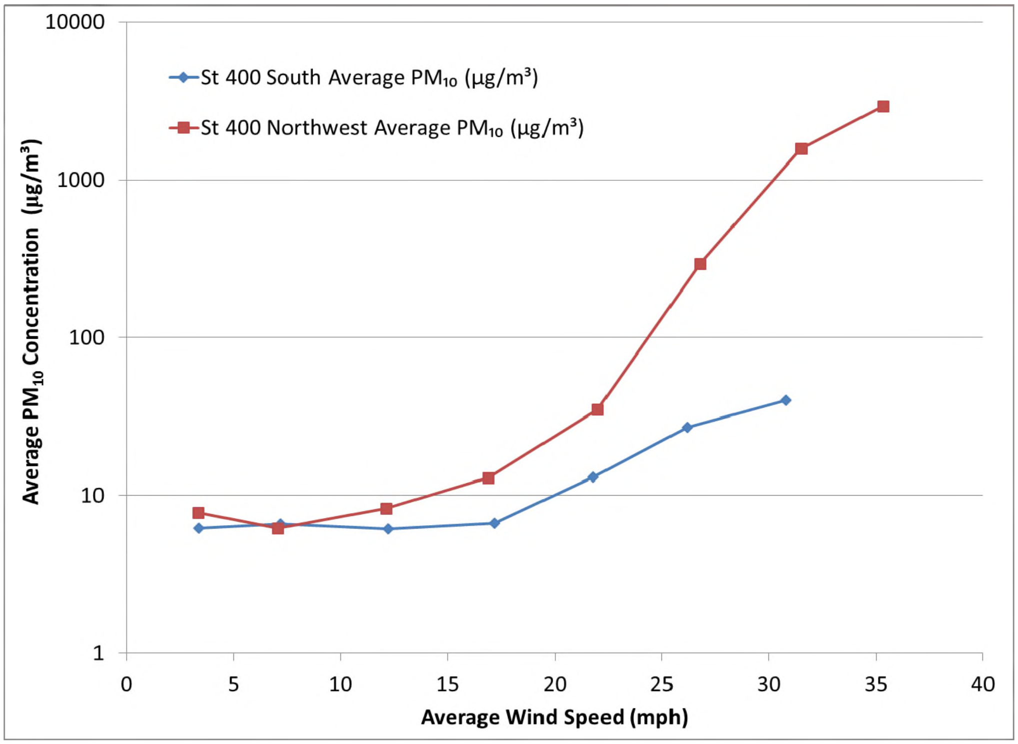

Figure 48. PM_{10} trends as a function of wind speed for Station 400 for CY2015. PM_{10} concentration plotted on a logarithmic scale to show a wide dynamic range of PM_{10} concentrations.

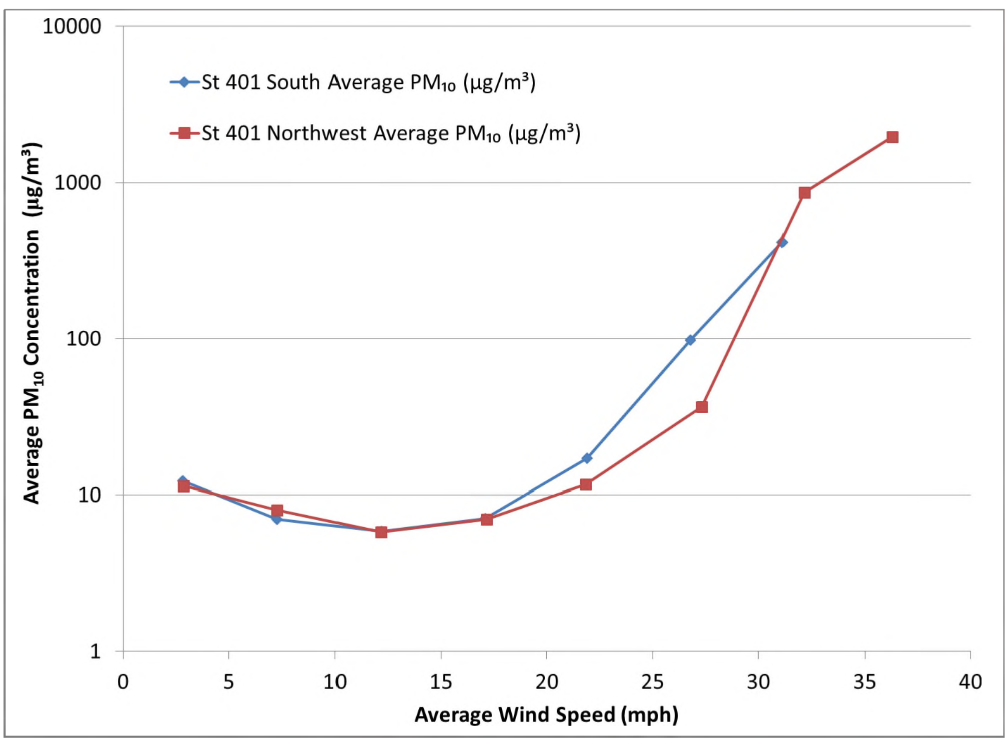

Figure 49. PM_{10} trends as a function of wind speed for Station 401 for CY2015. PM_{10} concentration plotted on a logarithmic scale to show a wide dynamic range of PM_{10} concentrations.

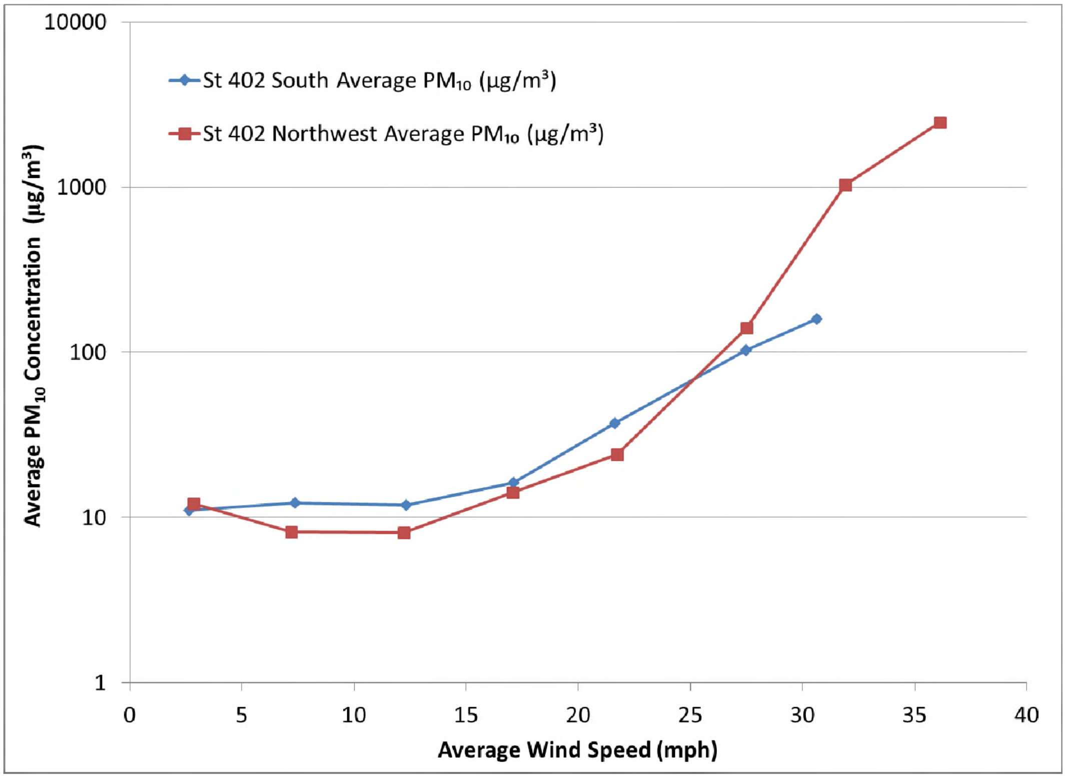

Figure 50. PM_{10} trends as a function of wind speed for Station 402 for CY2015. PM_{10} concentration plotted on a logarithmic scale to show a wide dynamic range of PM_{10} concentrations.

APRIL 15, 2015, WIND EVENT

Most dust transport occurs during high wind events that tend to be short in duration. The strongest wind events usually occur between March and May (see Tables B-1, B-2, and B-3 in Appendix B) and it is also during this time period that the highest PM_{10} concentrations are recorded. Figure 51 shows the wind rose graphs for all three monitoring stations at TTR for April 15, 2015. The wind rose graphs show the maximum wind gusts based on the three second readings saved every 10 minutes. Wind rose graphs show that the strongest winds during this wind event were coming from the northwest direction with a less strong and much less frequent component from the south. The wind gusts were over 64 km/hr (40 mph) between roughly 10:30 and 15:30 hours Pacific Daylight Saving Time (PDST). Figures 52 to 54 show detailed time series of wind speed and PM_{10} concentration. All three monitoring stations experienced very similar wind conditions and showed similar increases in PM_{10} mass concentrations. All three monitoring stations recorded PM_{10} concentrations in excess of 1,500 µg/m^3 between 10:30 and 15:30 hours PDST when the winds were at their strongest level for the day. The PM_{10} concentrations were below 100 µg/m^3 for wind speeds below 48 km/hr (30 mph).

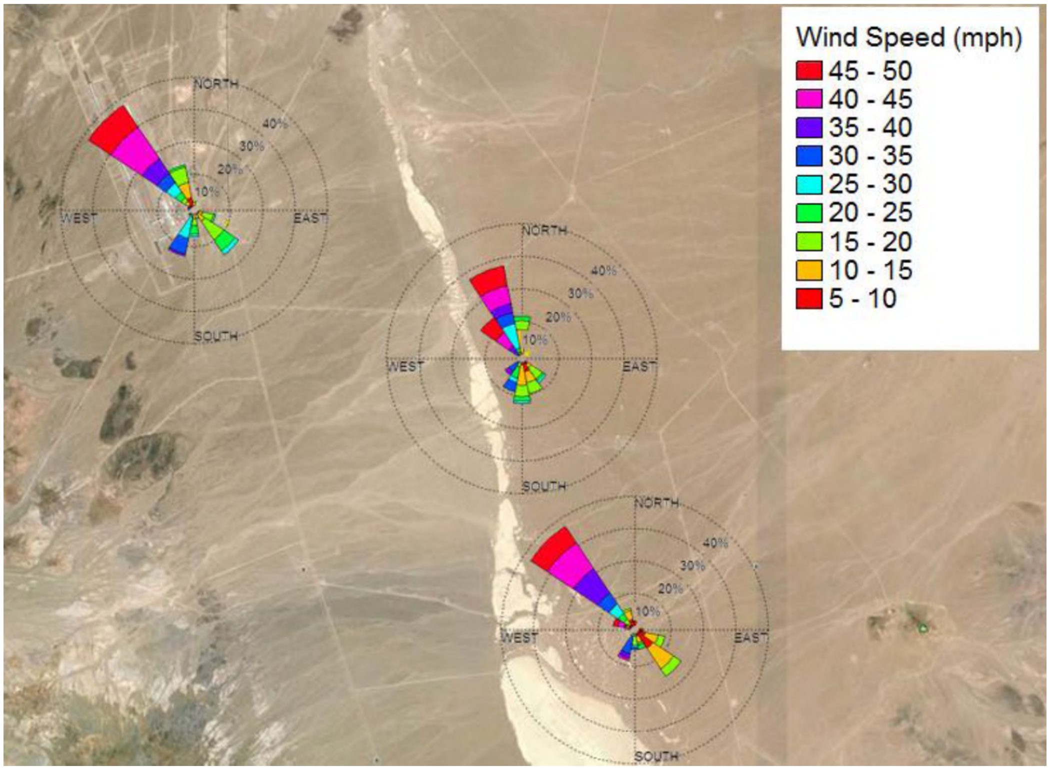

Figure 51. Wind roses for the monitoring stations for April 15, 2015.

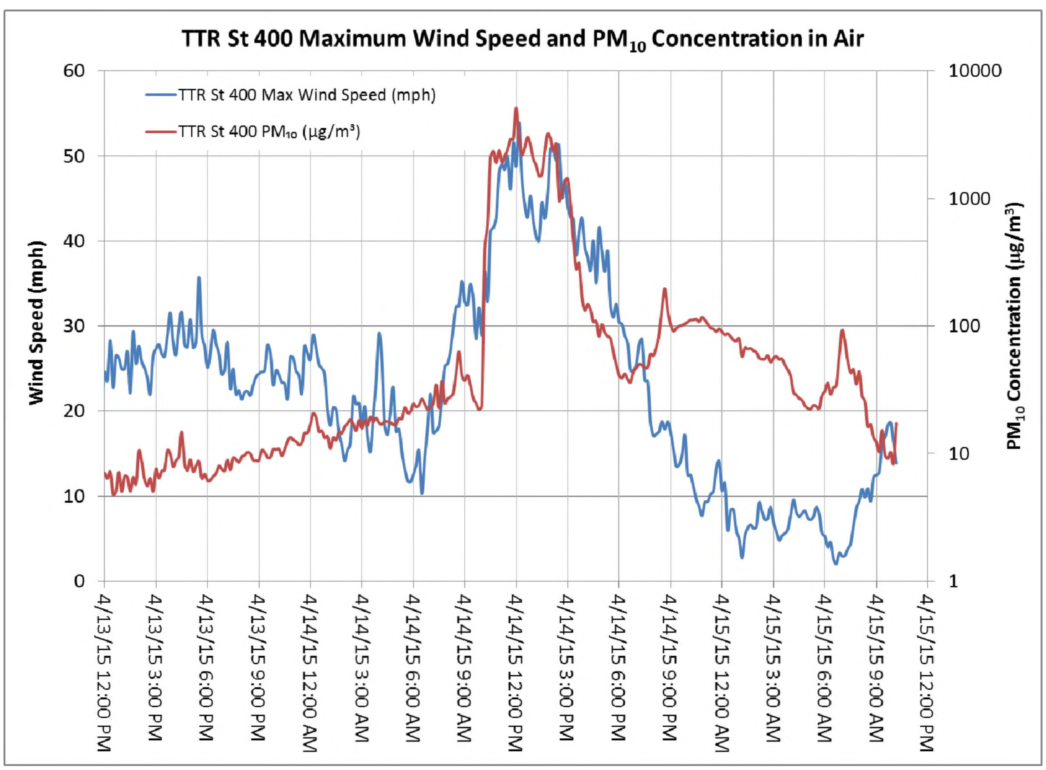

Figure 52. Wind speed and PM_{10} concentration at Station 400 on April 15, 2015.

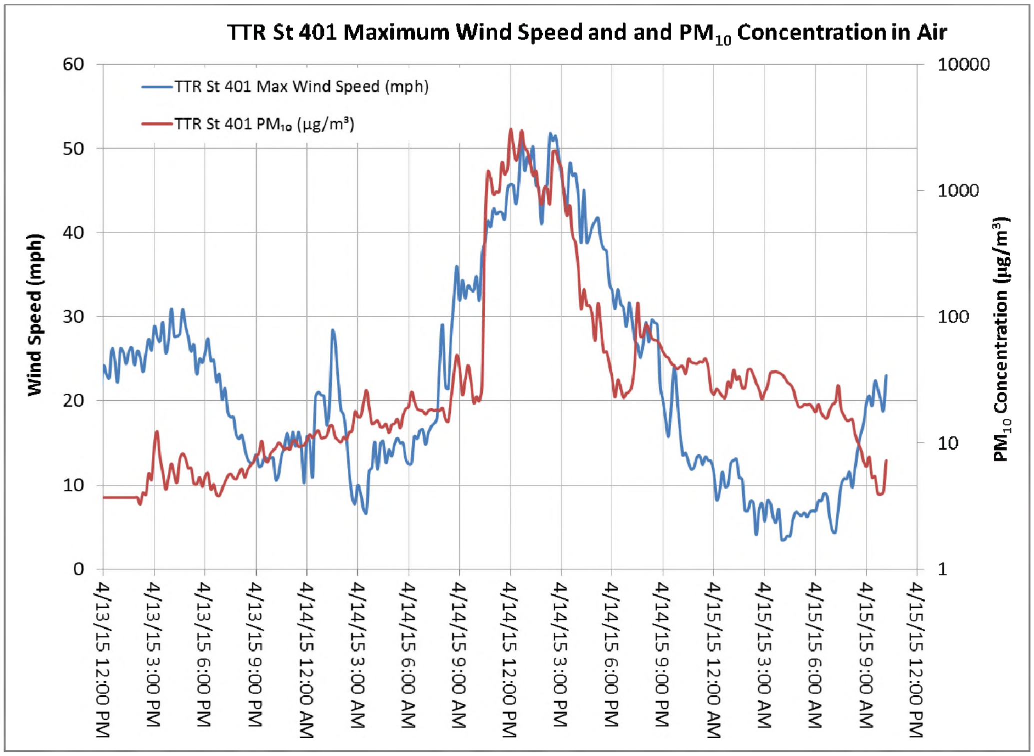

Figure 53. Wind speed and PM_{10} concentration at Station 401 on April 15, 2015.

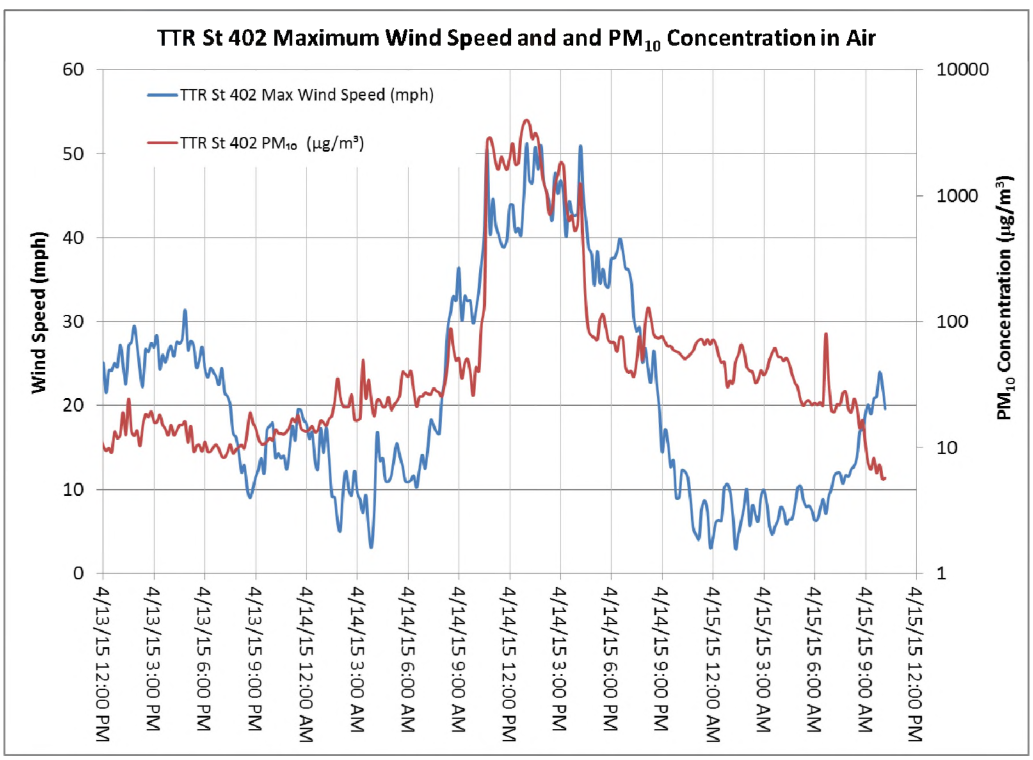

Figure 54. Wind speed and PM_{10} concentration at Station 402 on April 15, 2015.

DISCUSSION

Particle movement by saltation and suspension continues to be recorded at the TTR stations. As wind speed increases past a threshold of 24 to 32 km/hr (15 to 20 mph), saltation particle counts increase roughly exponentially. Station 402 has a somewhat higher saltation rate than Station 401. Saltation is strongly correlated with PM_{10} concentration, which indicates that saltation is important for initiating the suspension of finer material. The PM_{10} concentrations are generally low when wind speed is less than 24 km/hr (15 mph), which is the condition more than 90 percent of the time. In 2015, winds greater than 32 km/hr (20 mph) occurred approximately two percent of the time, but this is when most particle motion occurs, which reflects the exponential relationship observed between wind speed and PM_{10}. There was a higher frequency of winds above 57 km/hr (35 mph) and higher PM_{10} concentrations in CY2015 than were observed in CY2013 or CY2014.

To determine if radiological contaminants are being transported by wind from the Clean Slate sites, dust collected by air filters at the monitoring stations is analyzed for gross alpha, gross beta, and gamma spectroscopy and the gamma exposure rate is measured by the PIC instruments. Results from alpha spectroscopy performed on soil samples collected in saltation traps are new in 2015. Alpha spectroscopy will be performed on air filter samples in the future.

As in previous years, the comparison of the gross alpha, gross beta, and gamma exposure rate data from the TTR stations with those from regional CEMP stations suggest the TTR results reflect natural background conditions. Similarly, gamma spectroscopy identified only naturally occurring radionuclides with no detection of ^{241}Am (used as an indicator of plutonium isotopes).

By contrast, the alpha spectroscopy analyses for the saltation trap samples clearly indicate the presence of $^{239+240}$Pu at concentrations above background. With only two sample collection periods, interpretations must be considered preliminary, but the lack of consistent differences between the samples collected upwind and downwind from the fenced CAUs suggests that baseline concentrations of contaminants were already elevated in the area prior to BSNE trap placement. This is consistent with radiological surveys that have noted the existence of "substantial areas of contamination…outside the fence" (EG&G, 1979). The CAU closure strategy uses a risk-based approach, whereby acceptable contaminant concentrations are determined as a function of anticipated human exposure. As a result, the fence lines at the Clean Slate sites encircle areas of higher concentration and the presence of contamination outside the fences is expected, albeit at lower concentrations. The $^{239+240}$Pu concentrations measured in the trap samples are all below the risk-based action level.

Given that baseline conditions around the traps are assumed to be elevated compared with natural background, the collection of plutonium within the traps at concentrations higher than background cannot be interpreted as necessarily reflecting transport beyond the fence line. Nonetheless, the results do demonstrate that plutonium is moving by saltation in the environment. The traps are passive and only collect material that the wind has propelled into them. Therefore, the upwind and downwind capture indicates this movement is occurring both toward and away from the fenced area. Understanding whether or not one direction predominates is important for assessing the long-term effect of saltation and will be a focus of interpretation as more data are collected.

It is also important to recognize the spatial limitations of the monitoring network. The stations are located in one of the predominant wind directions (downwind of the sites for southerly winds), but no data are available for areas downwind of northwest winds, which are associated with the highest wind speeds. The Clean Slate sites are large and radiologic source and transport conditions certainly vary across them. Migration also may be a discontinuous process and only occur under specific, infrequent conditions. These limitations on the spatial and temporal coverage of current monitoring heighten the importance of another objective of the monitoring, which is to identify if there are conditions that could allow contaminant transport to occur.

CONCLUSIONS

The combined results of the meteorological and particle monitoring suggest that conditions for wind-borne contaminant migration exist at the Clean Slate sites. Although radionuclide-contaminated particulates from the Clean Slate I and III sites were not detected during air filter analyses or external radiation monitoring, plutonium above background was collected by saltation traps during 2015 and early 2016.

Samples collected on air filters show that the highest mean gross alpha and mean gross beta activities and highest mean gamma exposure rate were observed at Station 402 adjacent to Clean Slate I. Values reported for Station 400 (at the SNL ROC) are slightly lower than the Station 402 values and the maximum individual gross alpha measurement was from Station 400. Gamma spectroscopy analyses for all three sites identified only naturally occurring radionuclides.

The mean gross alpha values for the TTR stations are higher than those observed at four CEMP stations in the region but lower than two others. The mean gross beta measurements at Stations 400 and 401 are lower than the regional CEMP stations, and Station 402 is lower than two of the six compared CEMP stations. These comparisons suggest that the air filter samples at the TTR monitoring stations reflect natural (terrestrial and cosmic) sources that are approximately equivalent to levels observed at the surrounding CEMP stations.

Gamma exposure rates measured by PICs are similar to those measured at the CEMP station at Warm Springs Summit—although they are higher than rates at other CEMP stations—and within the range observed nationally for background levels of environmental (terrestrial and cosmic) gamma exposure rates in the United States (5.6 to 28.2 μR/hr; National Academy of Sciences, 1980). Most intervals of increased gamma values are coincident among the three TTR stations and also coincident with the Warm Springs Summit measurements. Many of these intervals coincide with precipitation events.

Alpha spectroscopy of material accumulated in saltation traps adjacent to Clean Slate I and III identified the presence of $^{239+240}Pu$ at concentrations above background, but below risk-based action levels. The presence of plutonium in traps collecting material both upwind and downwind of the fenced sites is consistent with previous radiological survey results showing low level contamination dispersed outside the fenced area. Given this, the collection of plutonium within the traps does not necessarily reflect transport of material beyond the fenced area, but it does demonstrate that plutonium is moving by saltation in the environment.

A strong correlation between high saltation values and high PM_{10} values suggests that saltation (driven by strong winds) contributes to fine dust emissions. However, wind speeds in excess of 32 km/hr (20 mph) occurred less than two percent of the time (roughly 170 hours) at the stations during CY2015 and occurred predominantly from the south or northwest. The highest wind speeds are commonly associated with the northwest direction. Annual precipitation averaged for the three stations in 2015 is 142.7 mm (5.62 in), above the long-term annual average measured at the Tonopah Airport (129.03 mm; 5.08 in). The annual amount varied from 122.4 mm (4.82 in) at Station 400 to 162.3 mm (6.39 in) at Station 401.

RECOMMENDATIONS

1. Add monitoring stations south/southeast of the Clean Slate sites so that they are collecting data downwind of the strongest dominant wind direction.
2. Analyze select air filters using alpha spectroscopy for comparison with the saltation trap results.
3. Collect samples from the saltation traps as frequently as collection rate allows, preferably every six months to minimize sample loss because of strong rains. More frequent collection will also enable mass and soil size distribution data to be associated more reliably with specific strong wind events.
4. Evaluate the combined saltation trap dataset in terms of meteorological and particulate data and radionuclide content.
5. Conduct a complete review of existing particle size data to determine if sufficient information exists to characterize PM_{10} and saltation material at the sites or if new sample collection is needed.
6. Establish a background monitoring station in terrain similar to the Clean Slate sites.

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APPENDIX A: QUALITY ASSURANCE PROGRAM

Although the current data collected for the TTR air monitoring study are considered for informational purposes to support conceptual models or guide investigations, the U.S. Department of Energy National Nuclear Administration Nevada Field Office (DOE/NNSA/NFO) Soils Activity Quality Assurance Plan (QAP) (2012) was used as a guideline to collect and analyze radiological data presented in the Radiological Assessment of Airborne Particulates section of this report. This QAP and the Desert Research Institute Quality Assurance Program Manual for the DOE Program (2010) ensures compliance with U.S. Department of Energy Order DOE O 414.1D, "Quality Assurance," which implements a quality management system to ensure the generation and use of quality data. The following items are addressed by the aforementioned QA documents:

- Data quality objectives (DQOs)
- Sampling plan development appropriate to satisfy the DQOs
- Environmental health and safety
- Sampling plan execution
- Sample analyses
- Data review
- Continuous improvement

Data Quality Objectives (DQOs)

The DQO process is a strategic planning approach that is used to plan data collection activities. It provides a systematic process for defining the criteria that a data collection design should satisfy. These criteria include when and where samples should be collected, how many samples to collect, and the tolerable level of decision errors for the study. The DQOs are unique to the specific data collection or monitoring activity and their defined level of use (in this case, informational purposes).

Measurement Quality Objectives (MQOs)

The MQOs are basically equivalent to DQOs for analytical processes. The MQOs provide direction to the laboratory concerning performance objectives or requirements for specific method performance characteristics. Default MQOs are established in the subcontract with the laboratory but can be altered to satisfy changes in the DQOs. The MQOs for the TTR air monitoring study are described in terms of precision, accuracy, representativeness, completeness, and comparability requirements. These terms are defined and discussed in the DOE/NNSA/NFO QAP.

Sampling Quality Assurance Program

Quality assurance (QA) in field operations for the TTR air monitoring study includes sampling assessment, surveillance, and oversight of the following supporting elements:

- The sampling plan, DQOs, and field data sheets accompanying the sample package.

- Database support for field and laboratory results, including systems for long-term storage and retrieval.
- Qualified personnel able and available to perform the required tasks.

Sample packages include the following items:

- Field notes confirming all observable information pertinent to sample collection.
- An Air Surveillance Network Sample Data form documenting air sampler parameters, collection dates and times, and total sample volumes collected.
- Chain-of-custody forms that also include some of the elements of the field notes.

This managed approach to sampling ensures that the sampling is traceable and enhances the value of the final data available to the project manager. The sample package also ensures that the field personnel responsible for sample collection have followed proper procedures for sample collection.

Data obtained in the course of executing field operations are entered in the documentation accompanying the sample package during sample collection and in the TTR Study database along with analytical results on their receipt and evaluation.

Hard copies of the completed sample packages are kept in the archived files. The analytical reports are kept in dedicated and secure archival systems that are protected and maintained in accordance with the Desert Research Institute's Computer Protection Program and hard copies are kept in the file archives.

Laboratory QA Oversight

Although the data for the TTR air monitoring study are for informational purposes, the main aspects of the DOE O 414.1D requirements are used as guidelines to evaluate laboratory services through review of the vendor laboratory policies formalized in a Laboratory Quality Assurance Plan (LQAP). The TTR study is assured of obtaining quality data from laboratory services through a multifaceted approach that involves specific procurement protocols, the conduct of quality assessments, and requirements for selected laboratories to have an acceptable QA Program. These elements are discussed below.

Procurement

Laboratory services are procured through subcontracts that establish the technical specifications required of the laboratory to provide the basis for determining compliance with those requirements and for evaluating overall performance. A subcontract is usually awarded on a "best value" basis determined by pre-award audits, but because of the specific requirement requested for gamma spectroscopy analysis (24 hour count duration) for the TTR study, the laboratory was procured on a sole proprietor basis. The laboratory was required to provide a review package that included the following items:

- All procedures pertinent to subcontract scope
- Environment, Health, and Safety Plan
- LQAP
- Example deliverables (hard copy and/or electronic)

- Proficiency testing (PT) results from the previous year from recognized PT programs
- Résumés
- Accreditations and certifications
- Licenses

Continuing Assessment

A continuing assessment of the selected laboratory involves ongoing monitoring of the laboratory's performance against the contract terms and conditions, part of which are the technical specifications. The following tasks support continuing assessment:

- Tracking schedule compliance.
- Reviewing analytical data deliverables.
- Monitoring the laboratory's adherence to the LQAP.
- Monitoring for continued successful participation in approved PT programs.

Data Review

Essential components of process-based QA are data checks, verification, validation, and data quality assessment to evaluate data quality and usability.

Data checks: Data checks are conducted to ensure accuracy and consistency of field data collection operations prior to and upon data entry into the TTR databases and data management systems.

Data verification: Data verification is defined as a compliance and completeness review to ensure that all laboratory data and sample documentation are present and complete. Sample preservation, chain-of-custody, and other field sampling documentation shall be reviewed during the verification process. Data verification ensures that the reported results entered in the TTR databases correctly represent the sampling and/or analyses performed and includes evaluation of quality control (QC) sample results.

Data validation: Data validation is the process of reviewing a body of analytical data to determine if it meets the data quality criteria defined in operating instructions. Data validation ensures that the reported results correctly represent the sampling and/or analyses performed, determines the validity of the reported results, and assigns data qualifiers (or "flags") if required. The process of data validation consists of the following:

- Evaluating the quality of the data to ensure that all project requirements are met.
- Determining the effect of not meeting those requirements on data quality.
- Verifying compliance with QA requirements.
- Checking QC values against defined limits.

- Applying qualifiers to analytical results in the TTR databases for the purposes of defining the limitations in the use of the reviewed data.

Operating instructions, procedures, applicable project-specific work plans, field sampling plans, QA plans, analytical method references, and laboratory statements of work may all be used in the data validation process. Documentation of data validation includes checklists, qualifier assignments, and summary forms.

Data quality assessment (DQA): The DQA is the scientific evaluation of data to determine if the data obtained from environmental data operations are of the right type, quality, and quantity to support their intended use. The DQA review is a systematic review against preestablished criteria to verify that the data are valid for their intended use.

2015 Sample QA Results

Assessments of QA were performed by the TTR air monitoring study, including the laboratory responsible for sample analyses. These assessments ensure that sample collection procedures, analytical techniques, and data provided by the subcontracted laboratory complies with TTR study requirements. Data were provided by the University of Nevada, Las Vegas, Radiation Services Laboratory for gross alpha, gross beta, and gamma spectroscopy analyses. A brief discussion of the 2015 results for laboratory duplicates, control samples, blank analyses, and interlaboratory comparison studies is provided along with summary tables in this section.

Laboratory Duplicates (Precision)

A laboratory duplicate is a sample that is handled and analyzed following the same procedures as the primary analysis. The relative percent difference (RPD) between the initial result and the corresponding duplicate result is a measure of the variability in the analytical process of the laboratory, mainly overall measurement uncertainty. The average absolute RPD was determined for calendar year 2015 samples and is listed in Table A-1. An RPD of zero indicates a perfect duplication of results of the duplicate pair, whereas an RPD greater than 100 percent generally indicates that a duplicate pair falls beyond QA requirements and is not considered valid for use in data interpretation. These samples are further evaluated to determine the reason for QA failure and if any corrective actions are required. Overall, the RPD values for all analyses indicate very good results with no samples exceeding an RPD of 100 percent.

Table A-1. Summary of laboratory duplicate samples for the TTR air monitoring study in 2015.

Analysis	Matrix	Number of Samples Reported[(a)]	Number of Samples Reported Above MDC[(b)]	Average Absolute RPD of Those Above MDC (%)[(c)]
Gross Alpha	Air	13	12	17.8
Gross Beta	Air	13	13	4.6
Gamma – Beryllium-7	Air	9	7	11.3
Gamma – Lead-210	Air	9	3	33.7

(a) Represents the number of laboratory duplicates reported for the purpose of monitoring precision.
(b) Represents the number of laboratory duplicate result sets reported above the minimum detectable concentration (MDC). If either the original laboratory analysis or its duplicate was reported below the detection limit, the precision was not determined.
(c) Reflects the average absolute RPD calculated for those field duplicates reported above the MDC.

The absolute RPD calculation is as follows:

$$Absolute\ RPD = \frac{|LD - LS|}{(LD + LS)/2} \ X \ 100\% \qquad (1)$$

where: LD = Field duplicate result

LS = Field sample result

Laboratory Control Samples (Accuracy)

Laboratory control samples (LCSs) (also known as matrix spikes) are performed by the subcontract laboratory to evaluate analytical accuracy, which is the degree of agreement of a measured value with the true or expected value. Samples of known concentration are analyzed using the same methods used for the project samples. The results are determined as the measured value divided by the true value, expressed as a percentage. To be considered valid, the results must fall within established control limits (or percentage ranges) for further analyses to be performed. The LCS results obtained for 2015 are summarized in Table A-2. The LCS results were satisfactory, with all samples falling within control parameters for the air sample matrix.

Table A-2. Summary of laboratory control samples for the TTR air monitoring study in 2015.

Analysis	Matrix	Number of LCS Results Reported	Number Within Control Limits[(a)]
Gross Alpha	Air	12	12
Gross Beta	Air	12	12
Gamma	Air	10	10

(a) Control limits are as follows: 78% to 115% for gross alpha, 87% to 115% for gross beta, 90% to 115% for gamma (^{137}Cs, ^{60}Co, ^{241}Am).

Laboratory Blank Analyses

Laboratory blank sample analyses are essentially the opposite of the LCSs discussed above. These samples do not contain any of the analyte of interest. Results of these analyses are expected to be "zero," or more accurately, below the MDC of a specific procedure. Blank analysis and control samples are used to evaluate overall laboratory procedures, including sample preparation and instrument performance. The laboratory blank sample results obtained for 2015 are summarized in Table A-3. The laboratory blank results were satisfactory with one beta blank sample falling outside of control parameters for the air sample matrix.

Table A-3. Summary of laboratory blank samples for the TTR air monitoring study in 2015.

Analysis	Matrix	Number of Blank Results Reported	Number within Control Limits[a]
Gross Alpha	Air	12	12
Gross Beta	Air	12	11
Gamma	Air	10	10

(a) Control limit is less than the MDC.

Interlaboratory Comparison Studies

Interlaboratory comparison studies are conducted by the subcontracted laboratories to evaluate their performance relative to other laboratories providing the same service. These types of samples are commonly known as "blind" samples, in which the expected values are known only to the program conducting the study. The analyses are evaluated and if found satisfactory, the laboratory is certified that its procedures produce reliable results. The interlaboratory comparison sample results obtained for 2015 are summarized in Table A-4.

Table A-4 shows the summary of interlaboratory comparison sample results for the subcontract radiochemistry laboratory. The laboratory participated in the QA Program administered by the Mixed Analyte Performance Evaluation Program (MAPEP) for gross alpha, gross beta, and gamma analyses. The subcontracted laboratory performed very well during the year by passing all of the parameters analyzed.

Table A-4. Summary of interlaboratory comparison samples of the radiochemistry laboratory for the TTR air monitoring study in 2015.

		MAPEP Results	
Analysis	Matrix	Number of Results Reported	Number Within Control Limits[a]
Gross Alpha	Air	2	2
Gross Beta	Air	2	2
Gamma	Air	2	2

(a) Control limits are determined by the individual interlaboratory comparison study.

REFERENCES

Desert Research Institute, 2010. *Desert Research Institute Quality Assurance Program Manual for the DOE Program,* October 2010.

U.S. Department of Energy, 2011. *Quality Assurance*. DOE O 414.1D.

U.S. Department of Energy, 2012. *Soils Activity Quality Assurance Plan*. National Nuclear Security Administration, Nevada Site Office report DOE/NV--1478.

APPENDIX B: SUMMARIES OF METEOROLOGICAL DATA

Table B-1. Station 400 summary of monthly and annual meteorological data.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL	VALUE
Wind Speed Avg (mph)	5.28	6.89	6.19	8.24	8.43	7.06	7.73	7.91	7.39	6.28	7.92	6.87	**AVG**	7.18
Wind Speed Max (mph)	18.95	27.25	23.51	35.33	26.48	25.78	37.50	30.53	23.41	28.30	31.46	27.59	**MAX**	37.50
Wind Speed Gust (mph)	30.10	37.63	38.73	53.92	42.89	41.57	50.78	46.69	36.75	45.74	44.64	42.31	**MAX**	53.92
Air Temperature Avg (deg F)	38.52	44.56	49.54	50.69	57.00	74.32	72.61	75.31	68.51	55.77	36.38	30.05	**AVG**	54.44
Air Temperature Min (deg F)	10.04	24.23	17.61	22.12	35.05	49.86	50.50	48.96	45.55	33.85	9.36	5.49	**MIN**	5.49
Air Temperature Max (deg F)	68.49	74.17	74.89	76.89	85.89	97.63	96.31	95.02	92.64	82.85	70.02	60.51	**MAX**	97.63
Relative Humidity Avg (%)	55.66	40.32	34.65	27.67	43.68	22.48	31.73	23.98	25.09	56.46	52.18	57.21	**AVG**	39.26
Relative Humidity Min (%)	13.05	8.08	7.04	5.60	9.46	5.10	8.13	5.35	7.60	9.95	7.91	13.53	**MIN**	5.10
Relative Humidity Max (%)	100.00	99.90	99.80	91.60	98.00	92.60	95.60	80.40	85.80	96.80	99.50	100.00	**MAX**	100.00
Total Precipitation (inch)	0.12	0.00	0.19	0.34	1.05	0.30	0.61	0.03	0.00	1.76	0.39	0.03	**TOTAL**	4.82
Soil Temperature Avg (deg F)	41.25	49.62	55.63	60.25	63.74	81.65	80.96	83.20	77.68	62.03	42.97	35.09	**AVG**	61.17
Soil Temperature Min (deg F)	26.29	37.05	33.81	43.64	47.08	61.92	66.94	67.71	64.65	46.29	29.65	25.89	**MIN**	25.89
Soil Temperature Max (deg F)	53.74	64.56	76.77	80.58	87.73	98.40	100.20	97.65	93.87	83.10	66.40	47.26	**MAX**	100.20
Soil Vol. Water Content Avg	0.14	0.14	0.15	0.14	0.18	0.18	0.19	0.15	0.13	0.19	0.16	0.13	**AVG**	0.15

Table B-1. Station 400 summary of monthly and annual meteorological data (continued).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL	VALUE
Soil Vol. Water Content Min	0.10	0.12	0.12	0.12	0.13	0.15	0.15	0.13	0.12	0.11	0.11	0.10	**MIN**	0.10
Soil Vol. Water Content Max	0.17	0.16	0.17	0.16	0.27	0.26	0.31	0.18	0.14	0.35	0.23	0.15	**MAX**	0.35
Solar Radiation Avg (ly)	5.46	8.07	10.73	13.97	13.02	15.88	14.48	13.84	11.77	7.64	6.27	4.94	**AVG**	10.51
Solar Radiation Max (ly)	34.92	41.80	49.97	57.97	60.81	63.65	60.12	55.91	53.67	40.77	38.62	33.80	**MAX**	63.65
Barometric P. Avg (in Hg)	24.70	24.59	24.63	24.50	24.46	24.56	24.60	24.61	24.57	24.61	24.56	24.56	**AVG**	24.58
Barometric P. Min (in Hg)	24.41	24.14	24.26	24.19	24.19	24.36	24.37	24.46	24.37	24.19	24.12	24.16	**MIN**	24.12
Barometric P. Max (in Hg)	24.94	24.84	24.84	24.77	24.64	24.71	24.79	24.78	24.75	24.81	24.84	24.90	**MAX**	24.94
PM_{10} Avg (μg/m^3)	9.92	9.58	29.79	6.43	7.27	6.80	6.98	6.68	2.88	4.02	3.11	33.80	**AVG**	10.61
PM_{10} Max (μg /m^3)	1052.8	276.2	3212.0	190.6	215.8	156.4	174.3	179.9	385.6	223.6	190.4	24.6	**MAX**	3212.0
$PM_{2.5}$ Avg (μg /m^3)	1.85	2.43	6.60	3.13	2.30	2.25	2.39	2.15	1.07	1.26	1.02	24.16	**AVG**	4.22
$PM_{2.5}$ Max (μg /m^3)	222.9	44.1	558.1	73.6	31.1	53.5	37.5	31.3	81.8	66.0	73.2	24.9	**MAX**	558.1

Table B-2. Station 401 summary of monthly and annual meteorological data.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL	VALUE
Wind Speed Avg (mph)	4.95	6.08	5.88	8.37	8.11	6.58	7.16	7.20	6.51	5.82	7.11	6.10	**AVG**	6.66
Wind Speed Max (mph)	21.76	27.01	23.96	37.73	26.34	22.18	25.65	30.94	24.22	26.15	33.34	30.24	**MAX**	37.73
Wind Speed Gust (mph)	29.67	37.48	40.41	51.73	45.59	41.06	41.50	45.67	35.07	38.43	45.96	41.21	**MAX**	51.73
Air Temperature Avg (deg F)	37.97	44.84	50.46	52.57	60.04	76.88	74.74	77.90	70.98	57.76	38.37	31.66	**AVG**	56.18
Air Temperature Min (deg F)	9.09	19.58	15.69	22.36	32.59	48.18	49.82	45.02	41.21	31.26	7.61	0.61	**MIN**	0.61
Air Temperature Max (deg F)	68.14	76.14	79.30	81.36	91.29	103.10	101.10	100.20	96.49	87.10	76.05	62.73	**MAX**	103.10
Relative Humidity Avg (%)	61.76	47.30	41.10	32.55	48.59	27.79	38.33	29.42	31.04	65.33	61.71	64.58	**AVG**	45.79
Relative Humidity Min (%)	16.06	13.90	7.25	7.87	12.36	6.71	10.51	7.11	10.20	16.63	12.45	17.48	**MIN**	6.71
Relative Humidity Max (%)	93.90	95.20	93.90	88.90	96.10	95.20	94.80	84.10	91.80	97.50	93.50	92.40	**MAX**	97.50
Total Precipitation (inch)	0.20	0.04	0.19	0.16	1.47	0.14	1.64	0.00	0.01	2.11	0.41	0.02	**TOTAL**	6.39
Soil Temperature Avg (deg F)	37.00	45.92	52.65	59.18	64.33	79.56	78.03	81.01	75.37	59.58	40.78	32.67	**AVG**	58.84
Soil Temperature Min (deg F)	25.73	36.12	35.22	46.71	48.22	64.06	66.25	68.86	63.82	45.69	29.98	25.18	**MIN**	25.18
Soil Temperature Max (deg F)	46.89	56.26	69.51	74.84	83.37	93.43	96.84	91.36	87.82	76.96	61.30	42.15	**MAX**	96.84

Table B-2. Station 401 summary of monthly and annual meteorological data (continued).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL	VALUE
Soil Vol. Water Content Avg	0.16	0.17	0.18	0.14	0.19	0.17	0.25	0.14	0.11	0.24	0.21	0.18	**AVG**	0.18
Soil Vol. Water Content Min	0.12	0.16	0.16	0.12	0.13	0.13	0.12	0.11	0.10	0.10	0.15	0.12	**MIN**	0.10
Soil Vol. Water Content Max	0.18	0.19	0.20	0.17	0.30	0.23	0.47	0.17	0.12	0.33	0.25	0.20	**MAX**	0.47
PM_{10} Avg (µg/m^3)	27.77	10.80	16.86	20.70	5.71	7.39	7.84	9.12	7.82	2.65	7.37	7.28	**AVG**	10.94
PM_{10} Max (µg /m^3)	4964.4	3204.7	4191.2	3034.3	81.7	204.7	275.9	582.3	224.4	352.4	809.0	3679.5	**MAX**	4964.4
$PM_{2.5}$ Avg (µg /m^3)	1.04	1.71	2.69	6.95	3.17	3.21	3.20	3.86	3.23	1.29	2.30	1.48	**AVG**	2.84
$PM_{2.5}$ Max (µg /m^3)	56.5	54.0	58.1	639.7	33.6	39.7	88.6	79.5	52.3	47.9	253.4	127.4	**MAX**	639.7

Table B-3. Station 402 summary of monthly and annual meteorological data.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL	VALUE
Wind Speed Avg (mph)	4.48	5.67	5.45	8.04	7.81	6.32	7.14	6.98	6.41	5.64	6.93	6.06	**AVG**	6.41
Wind Speed Max (mph)	19.51	24.22	24.97	36.85	25.77	22.29	30.78	32.76	23.89	24.96	32.95	31.50	**MAX**	36.85
Wind Speed Gust (mph)	29.08	33.68	38.87	51.22	43.99	36.61	48.74	44.42	41.14	37.78	47.27	44.21	**MAX**	51.22
Air Temperature Avg (deg F)	35.09	41.90	47.30	49.55	56.86	73.24	72.51	74.39	67.05	54.82	34.78	27.76	**AVG**	52.94
Air Temperature Min (deg F)	5.32	16.00	13.17	20.18	29.17	44.77	47.46	42.51	35.22	30.16	5.05	-6.88	**MIN**	-6.88
Air Temperature Max (deg F)	65.91	72.86	76.33	78.51	88.07	99.84	97.63	96.78	92.79	83.97	72.27	58.82	**MAX**	99.84
Relative Humidity Avg (%)	61.96	46.63	38.60	28.82	45.53	23.45	34.02	25.56	26.95	65.13	60.96	63.82	**AVG**	43.45
Relative Humidity Min (%)	12.93	9.30	2.41	3.90	6.87	2.57	5.99	3.15	6.22	12.46	6.59	10.99	**MIN**	2.41
Relative Humidity Max (%)	100.00	100.00	100.00	91.80	99.50	96.30	97.70	82.50	87.60	99.10	99.80	99.40	**MAX**	100.00
Total Precipitation (inch)	0.25	0.07	0.13	0.18	1.00	0.08	0.92	0.00	0.00	2.46	0.50	0.05	**TOTAL**	5.64
Soil Temperature Avg (deg F)	35.06	43.12	49.72	56.71	62.79	80.18	78.71	80.67	72.63	55.28	37.10	30.67	**AVG**	56.89
Soil Temperature Min (deg F)	21.56	34.01	31.82	41.52	45.91	61.39	65.70	66.43	58.98	41.07	25.57	20.35	**MIN**	20.35
Soil Temperature Max (deg F)	46.37	53.38	66.83	76.68	84.88	95.13	96.69	94.95	85.06	73.08	55.24	41.59	**MAX**	96.69
Soil Vol. Water Content Avg	0.11	0.12	0.11	0.09	0.12	0.11	0.14	0.08	0.06	0.18	0.15	0.11	**AVG**	0.11

Table B-3. Station 402 summary of monthly and annual meteorological data (continued).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL	VALUE
Soil Vol. Water Content Min	0.07	0.11	0.10	0.08	0.08	0.08	0.08	0.07	0.06	0.06	0.09	0.08	**MIN**	0.06
Soil Vol. Water Content Max	0.14	0.14	0.12	0.10	0.19	0.15	0.21	0.10	0.07	0.28	0.22	0.14	**MAX**	0.28
Solar Radiation Avg (ly)	10.09	15.76	20.58	26.68	23.96	28.69	26.56	26.23	22.57	14.07	11.87	9.76	**AVG**	19.74
Solar Radiation Max (ly)	61.24	79.99	99.17	102.90	109.80	111.00	102.40	99.26	103.60	85.24	69.33	60.47	**MAX**	111.00
Barometric P. Avg (in Hg)	24.82	24.72	24.75	24.61	24.58	24.67	24.71	24.73	24.69	24.73	24.67	24.65	**AVG**	24.69
Barometric P. Min (in Hg)	24.53	24.26	24.38	24.31	24.31	24.47	24.48	24.57	24.48	24.32	24.23	24.25	**MIN**	24.23
Barometric P. Max (in Hg)	25.06	24.97	24.97	24.88	24.76	24.82	24.90	24.90	24.86	24.94	24.94	25.00	**MAX**	25.06
PM_{10} Avg (µg/m^3)	3.50	9.58	12.75	32.56	11.26	16.96	21.42	23.73	15.88	5.04	10.75	6.38	**AVG**	14.15
PM_{10} Max (µg /m^3)	159.3	1719.1	1296.3	3999.5	575.3	763.4	1685.4	4134.2	782.1	1111.5	508.3	1482.0	**MAX**	4134.2
$PM_{2.5}$ Avg (µg /m^3)	1.09	3.80	4.59	10.69	4.39	4.27	5.92	6.73	4.46	1.53	2.80	1.85	**AVG**	4.34
$PM_{2.5}$ Max (µg /m^3)	45.9	909.6	445.3	1100.1	132.6	74.5	492.4	1418.9	334.6	221.5	146.7	359.3	**MAX**	1418.9

APPENDIX C: DAILY AVERAGE METEOROLOGICAL AND ENVIRONMENTAL DATA FOR TTR MONITORING STATIONS 400, 401, AND 402 DURING CY2015

Tonopah Test Range Station 400 CY2015

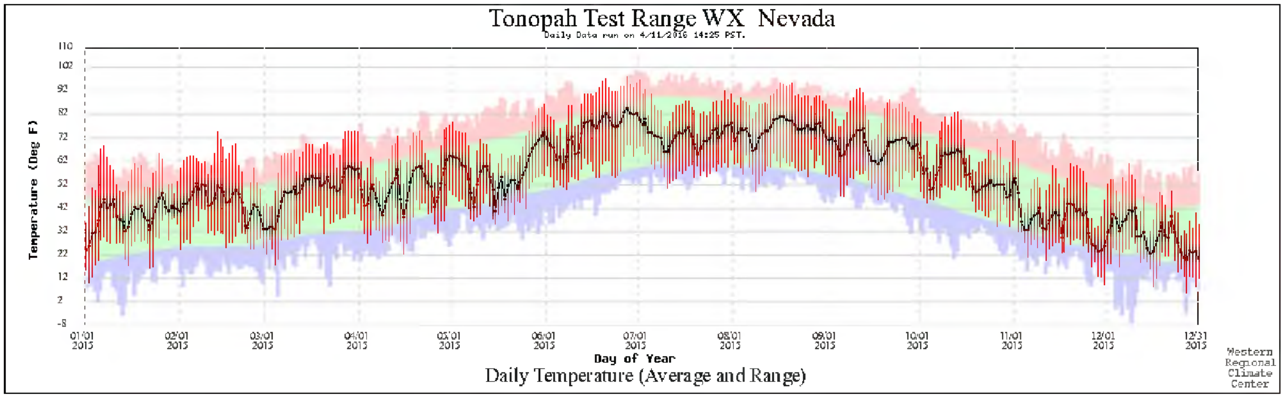

Figure C-1. Graphical summary of temperature data collected by the TTR Station 400 from January 1, 2015, until December 31, 2015. The underlying pastel colors represent the period-of-record extremes (red and blue) and averages (green).

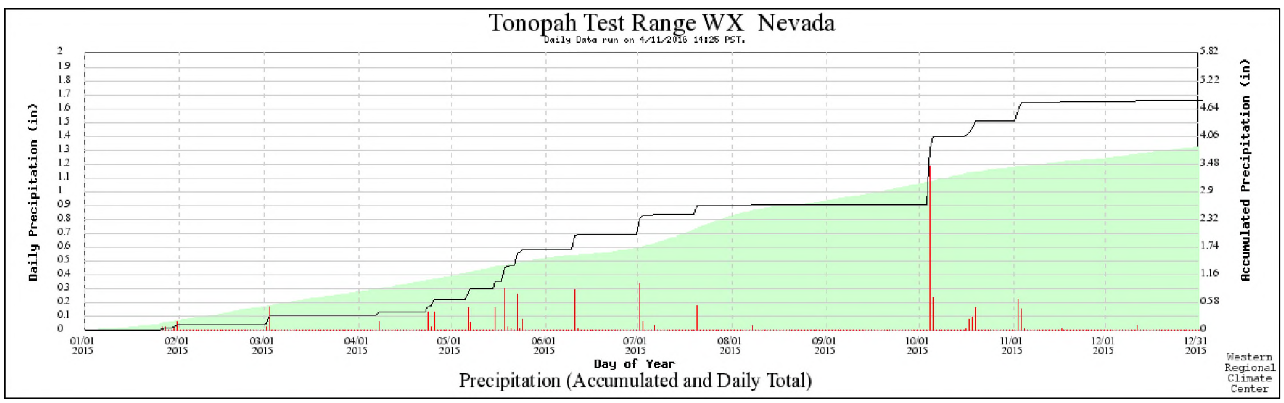

Figure C-2. Graphical summary of precipitation data, daily total (red bars) and accumulated (black line), collected by the TTR Station 400 from January 1, 2015, until December 31, 2015. The underlying light green shaded area represents the station period-of-record average precipitation accumulation.

Tonopah Test Range Station 400 CY2015

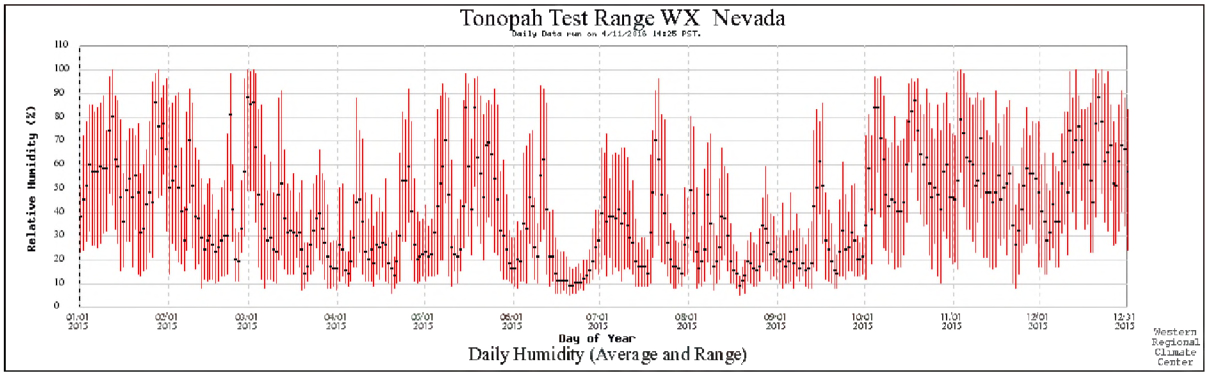

Figure C-3. Graphical summary of the humidity data—daily maximum and minimum (red bar), and average (black mark)—collected by the TTR Station 400 from January 1, 2015, until December 31, 2015.

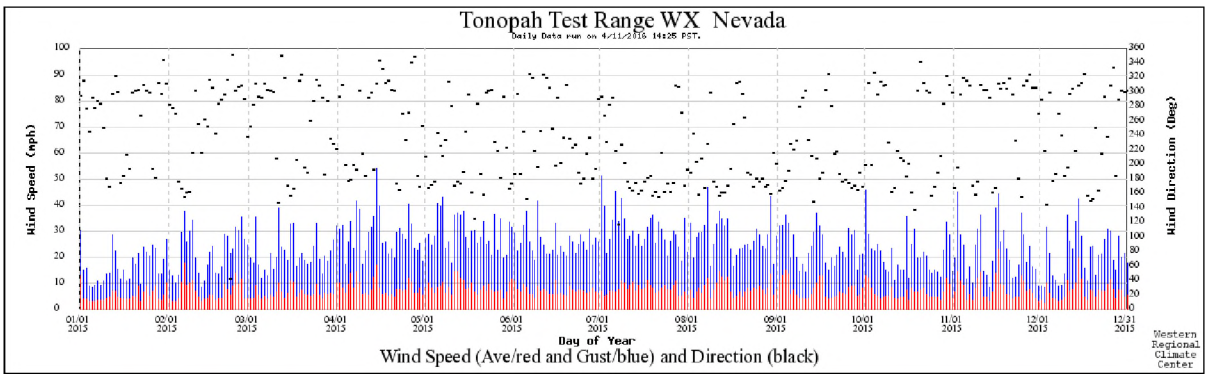

Figure C-4. Graphical summary of wind speed (daily average: red; daily peak gust: blue) and direction (black marks) data collected by the TTR Station 400 from January 1, 2015, until December 31, 2015.

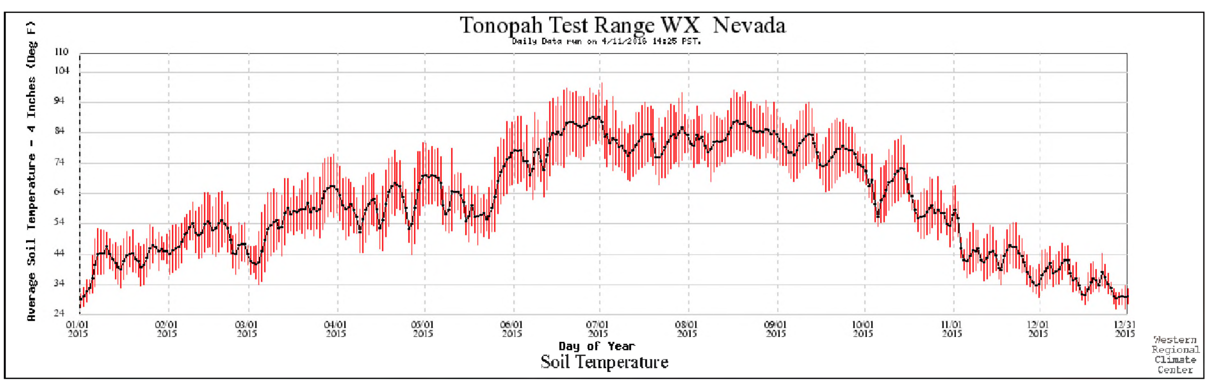

Figure C-5. Graphical summary of soil temperature data—daily maximum and minimum (red bar), and average (black line)—collected by the TTR Station 400 from January 1, 2015, until December 31, 2015.

Tonopah Test Range Station 400 CY2015

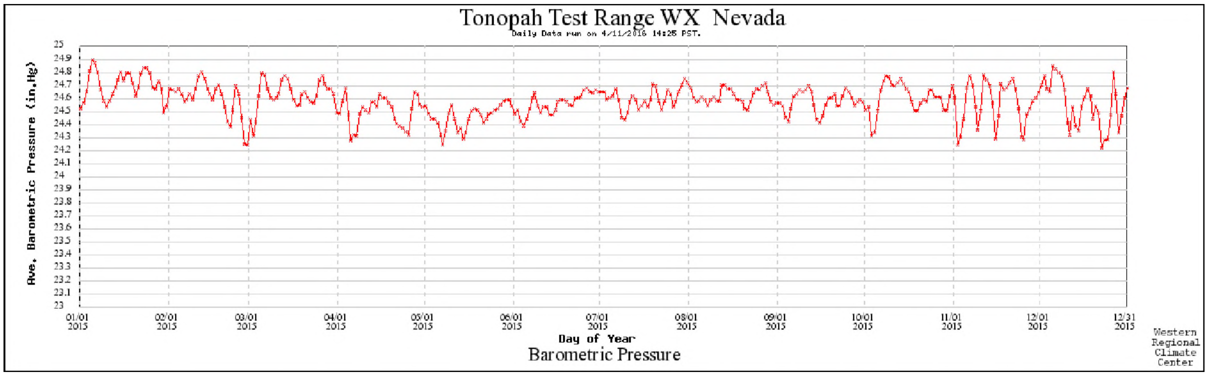

Figure C-6. Graphical summary of the daily average barometric pressure data collected by the TTR Station 400 from January 1, 2015, until December 31, 2015.

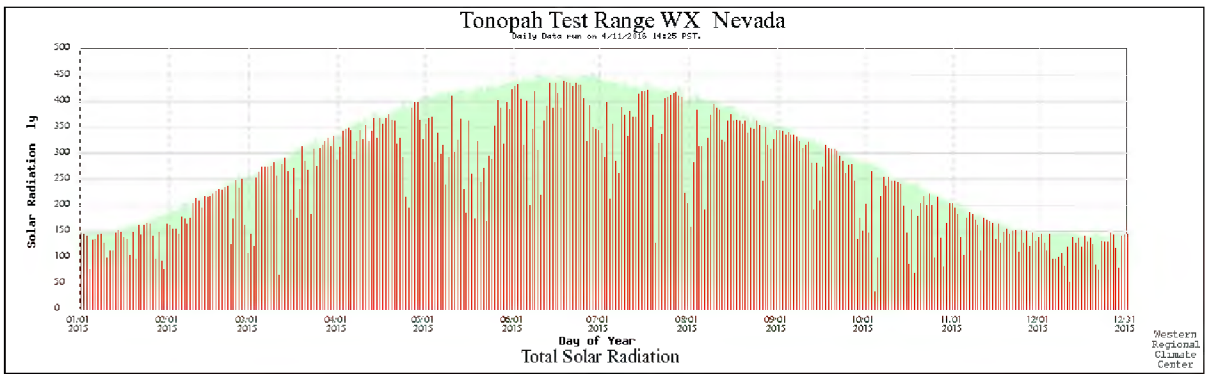

Figure C-7. Graphical summary of daily total solar radiation (red bar) data collected by the TTR Station 400 from January 1, 2015, until December 31, 2015. The underlying light green shaded area represents the station period-of-record maximum daily solar radiation.

Clean Slate III Station 401 CY2015

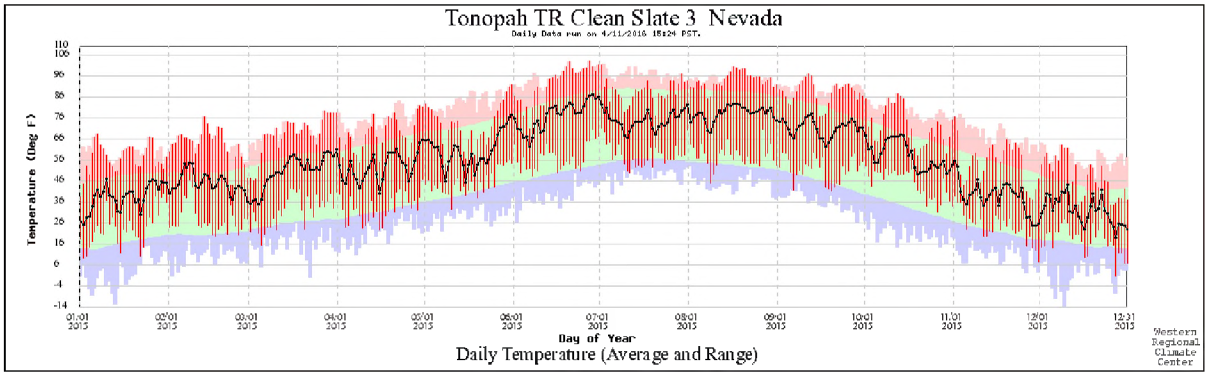

Figure C-8. Graphical summary of temperature data collected by the Clean State III station from January 1, 2015, until December 31, 2015. The underlying pastel colors represent the period-of-record extremes (red and blue) and averages (green).

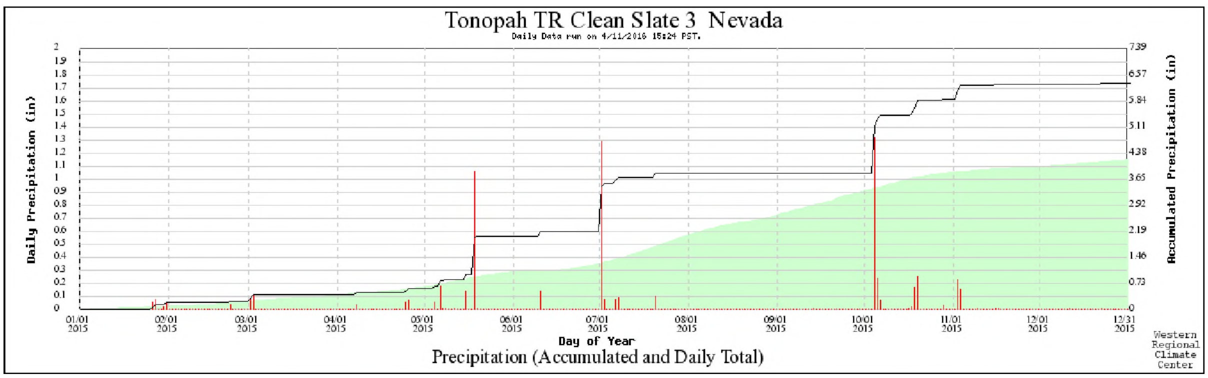

Figure C-9. Graphical summary of precipitation data—daily total (red bars) and accumulated (black line)—collected by the Clean State III station from January 1, 2015, until December 31, 2015. The underlying light green shaded area represents the station period-of-record average precipitation accumulation.

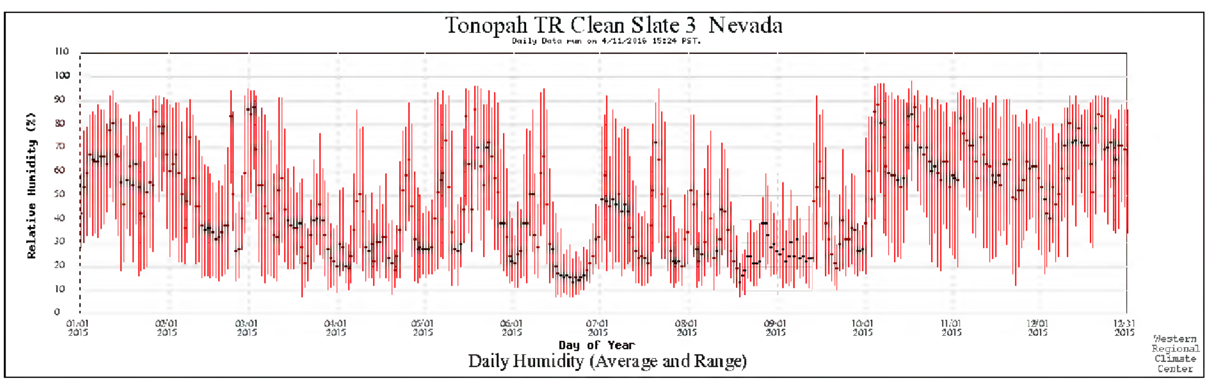

Figure C-10. Graphical summary of the humidity data—daily maximum and minimum (red bar) and average (black mark)—collected by the Clean State III station from January 1, 2015, until December 31, 2015.

Clean State III Station 401 CY2015

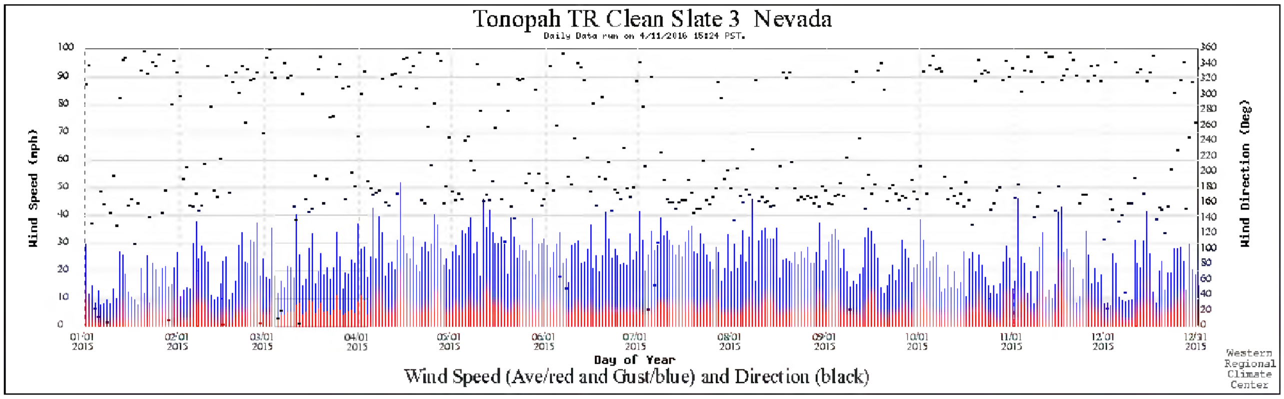

Figure C-11. Graphical summary of wind speed (daily average, red; daily peak gust, blue) and direction (black marks) data collected by the Clean State III station from January 1, 2015, until December 31, 2015.

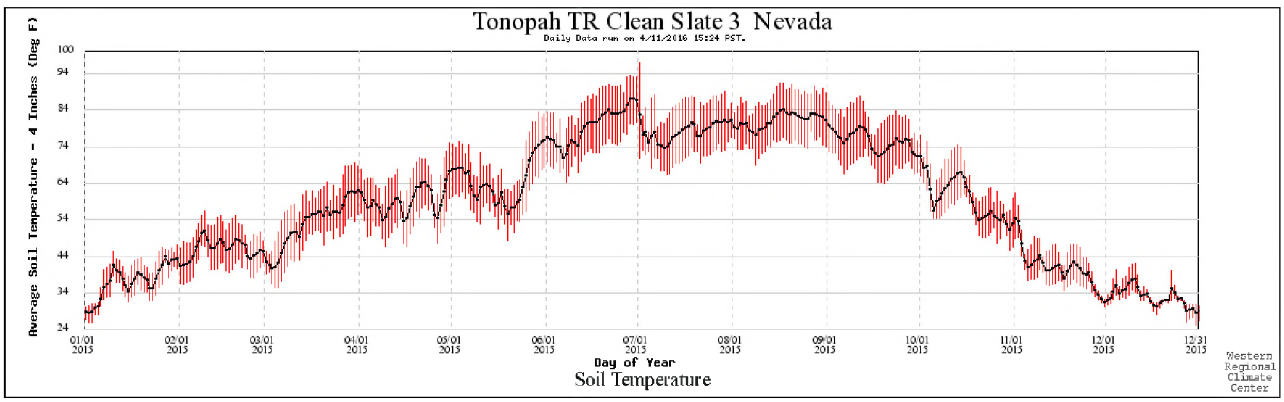

Figure C-12. Graphical summary of soil temperature data—daily maximum and minimum (red bar) and average (black line)—collected by the Clean State III station from January 1, 2015, until December 31, 2015.

Clean Slate I Station 402 CY2015

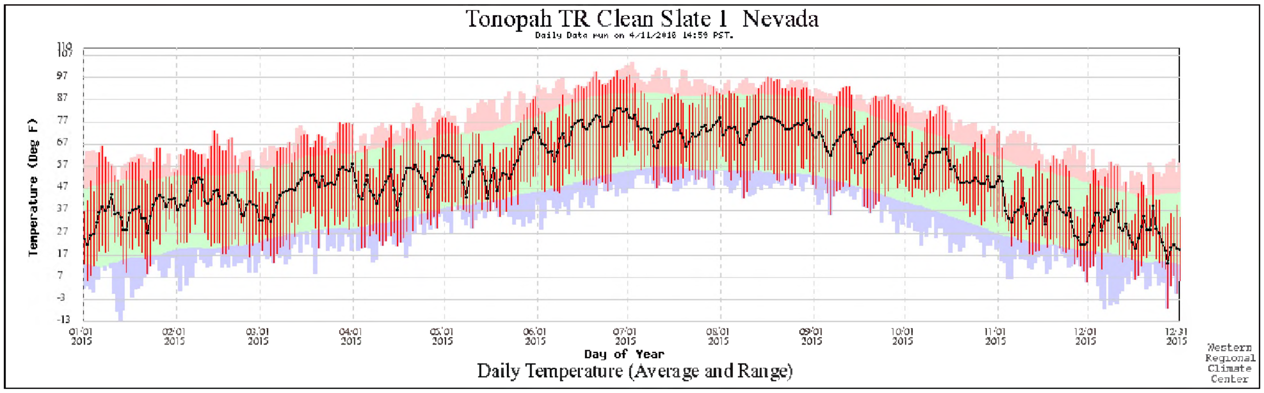

Figure C-13. Graphical summary of temperature data collected by the Clean Slate I station from January 1, 2015, until December 31, 2015. The underlying pastel colors represent the period-of-record extremes (red and blue) and averages (green).

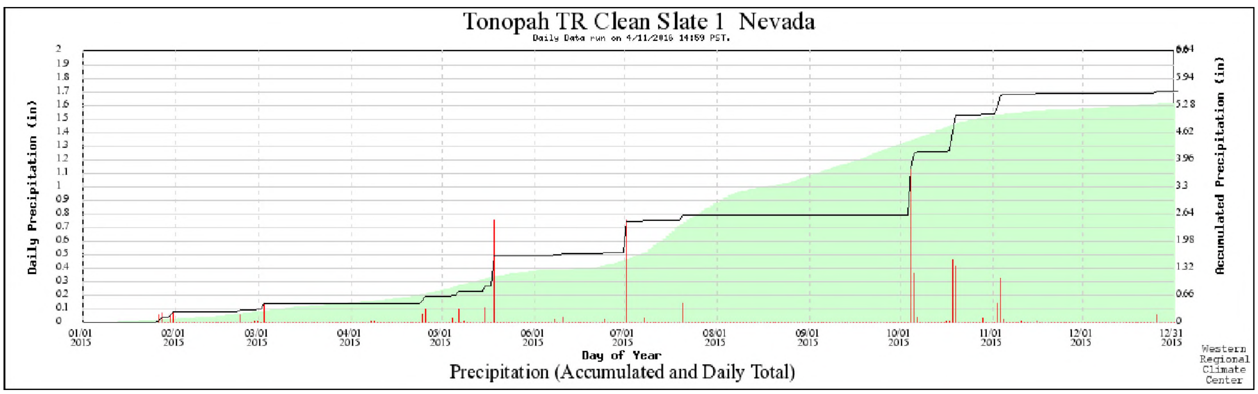

Figure C-14. Graphical summary of precipitation data, daily total (red bars) and accumulated (black line), collected by the Clean Slate I station from January 1, 2015, until December 31, 2015. The underlying light green shaded area represents the station period-of-record average precipitation accumulation.

Clean Slate I Station 402 CY2015

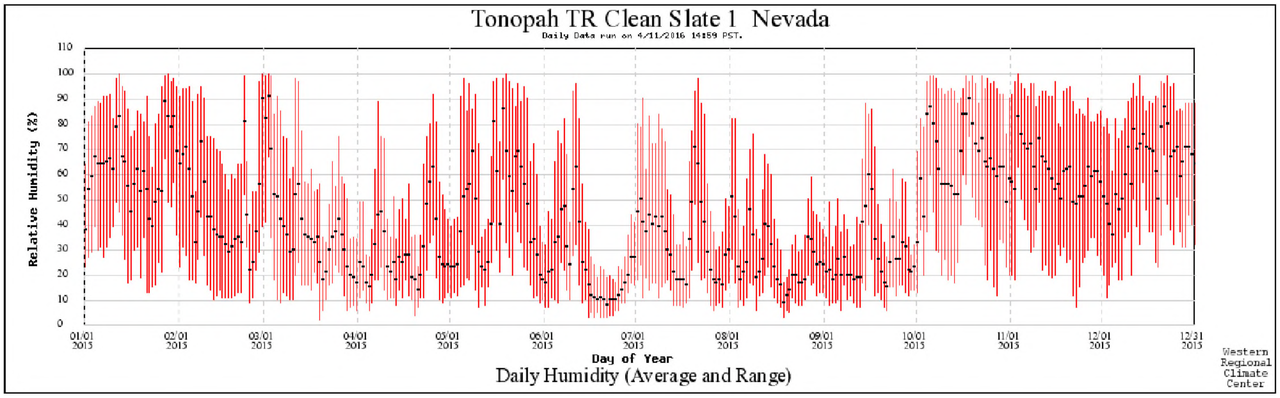

Figure C-15. Graphical summary of the humidity data, daily maximum and minimum (red bar) and average (black mark), collected by the Clean Slate I station from January 1, 2015, until December 31, 2015.

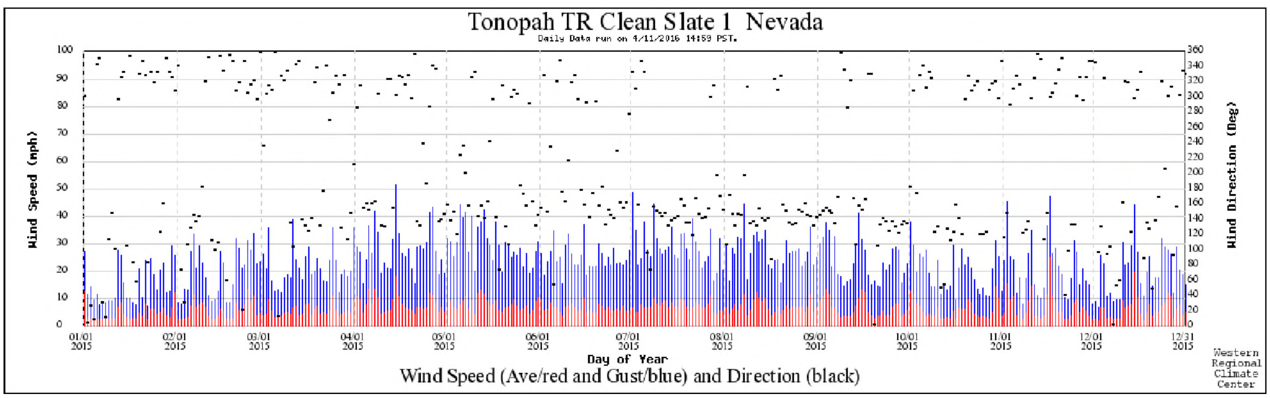

Figure C-16. Graphical summary of wind speed (daily average: red; daily peak gust: blue) and direction (black marks) data collected by the Clean Slate I station from January 1, 2015, until December 31, 2015.

Clean Slate I Station 402 CY2015

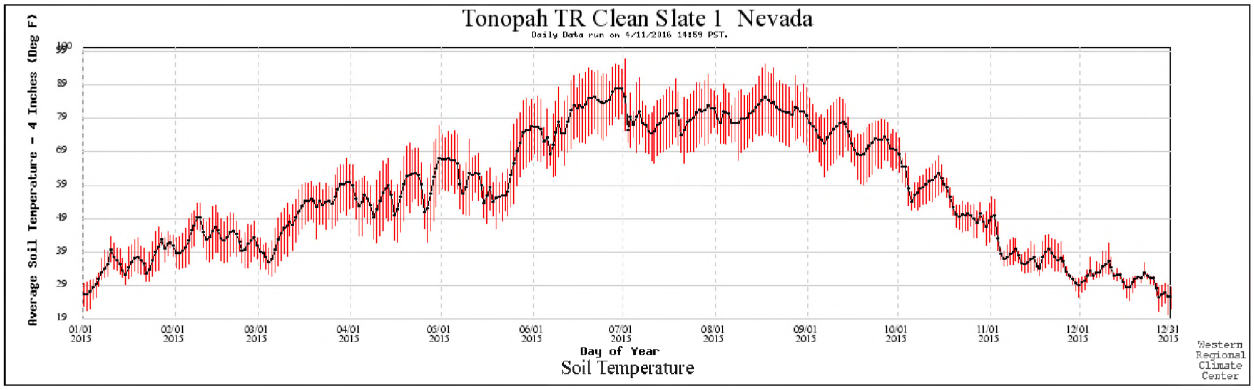

Figure C-17. Graphical summary of soil temperature data—daily maximum and minimum (red bar) and average (black line)—collected by the Clean Slate I station from January 1, 2015, until December 31, 2015.

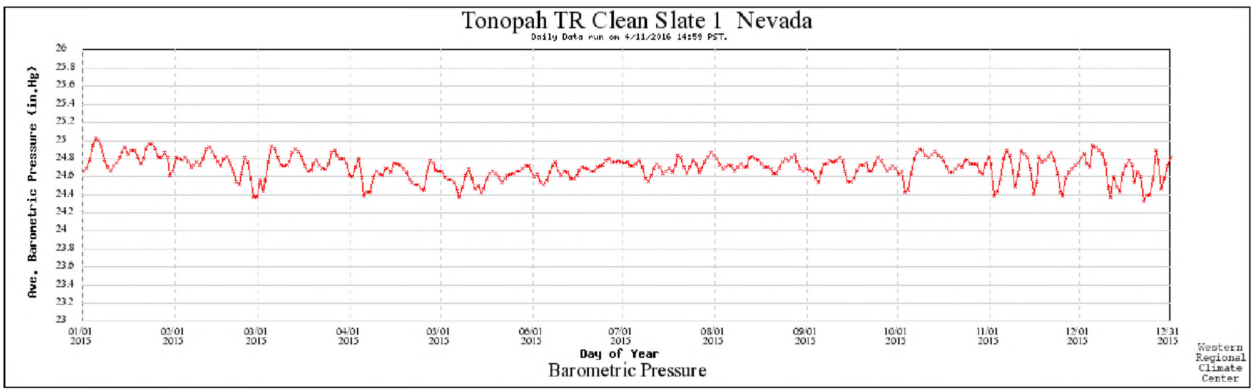

Figure C-18. Graphical summary of the daily average barometric pressure data collected by the Clean Slate I station from January 1, 2015, until December 31, 2015.

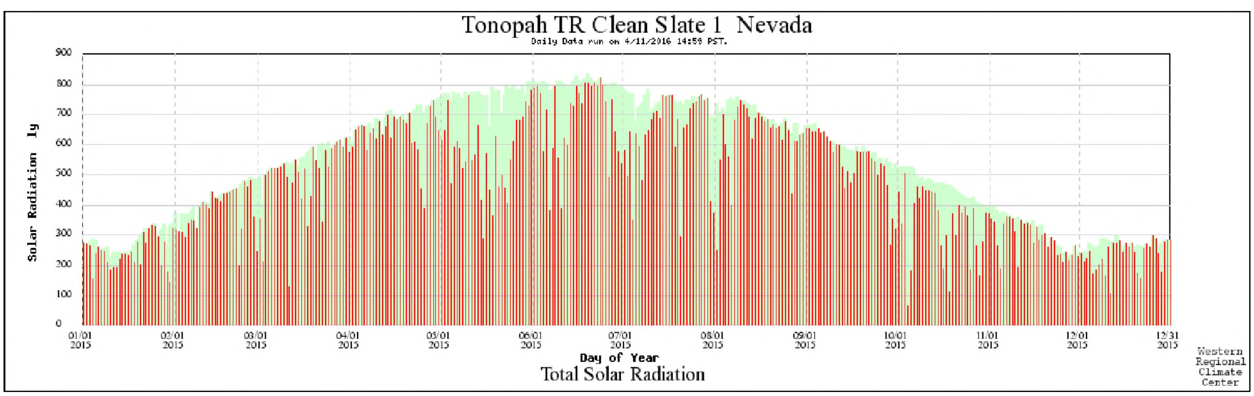

Figure C-19. Graphical summary of daily total solar radiation (red bar) data collected by the Clean Slate I station from January 1, 2015, until December 31, 2015. The underlying light green shaded area represents the station period-of-record maximum daily solar radiation.

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